THE UNIVERSITY OF ALBERTA

COMPUTER ASSISTED IRRIGATION WATER MANAGEMENT

by

JAMES MICHAEL BYRNE

A THESIS

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OF MASTER OF SCIENCE IN WATER RESOURCES

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

SPRING, 1983

United States Department of Agriculture
Agricultural Research Service
Western Region
Pacific Northwest Area
Snake River Conservation Research Center
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January 18, 1983

James Byrne
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Dear Mr. Byrne:

Permission is hereby granted for you to include the published material in your M.Sc. thesis as requested by your letter of Nov. 3, 1982 (copy attached).

Best regards to you as you complete your thesis. I would like to have a copy of the abstract of your thesis.

Sincerely,

James L. Wright

JAMES L. WRIGHT
Supervisory Soil Scientist

Attachment

Sorry for the delay.

James Byrne
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James L. Wright
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Kimberley, Idaho 83341

November 3rd, 1982

Dear Dr. Wright:

In our recent telephone converstion, I indicated a need for written permission to include material published by M. E. Jensen and yourself in an M.Sc. thesis. The following explanation will hopefully provide you with a clear picture of the situation and my request.

I am a graduate student with the Department of Civil Engineering, University of Alberta, in Edmonton. A critical portion of my thesis (computerized irrigation scheduling) is based upon the publication

Jensen,M.E. and Wright,J.L.
The Role of Evapotranspiration Models in Irrigation Scheduling.
Transactions of the ASAE 1978.

I would like to include reproductions of the following information/figures from your paper in my thesis:

1). Figure 2 Distribution of daily errors in estimated ET compared with measured ET for alfalfa at Kimberley, ID, 1968-1971.

2). Figure 4 Example confidence limits at the 95 percent probability level associated with irrigation scheduling after monitoring on 30 June.

3). Information given in the text of the paper on reduction in standard error in estimated

ET for Kimberley; ie.

standard error (inches)	time (days)
0.5	4
0.33	9
0.2	25

A letter of permission from the original authors for inclusion of previously copyrighted material in a thesis is a prerequisite of the National Library of Canada.

I enjoyed our brief exchange of ideas over the telephone. Hopefully we will have an opportunity to discuss a few topics of mutual interest in the future. If I may assist you in any way in the future, please call or write me at the Department of Civil Engineering. I'll will be involved in flatland hydrology research at the University of Alberta for the next 2 or 3 years.

Sincerely,

Jim Byrne

James Byrne

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November 25, 1982

Your file Votre référence

Our file Notre référence

665.1

Mr. James Byrne
Department of Civil Engineering
University of Alberta
EDMONTON, Alberta
T6G 2G7

Dear Jim:

Thank you for your letter of November 17 requesting the use of the revised crop coefficient curves developed by Mr. E. H. Hobbs of our Soil Science Section. These curves will appear in a revised version of Publication No. 1590, "Scheduling Irrigation to Meet Crop Demands." The revision is authored by E. H. Hobbs and K. K. Krogman and will be published in 1983 as a technical bulletin by the Research Branch, Agriculture Canada.

Since, these data are unpublished at the time of their intended use, our permission for you to include the plots in your M.Sc. thesis and in a report to the Alberta Environmental Research Trust is subject to the following conditions:-

- A general acknowledgement of the Agriculture Canada Research Station, Lethbridge, for access to these data, in the completed report.

- Where appropriate within the reports, a bibliographic citation of Publication No. 1590 or the revised version (in press).

- Provision of a copy of the completed thesis and report (on a confidential basis if required) to the Director, Lethbridge Research Station.

- A letter from you acknowledging and agreeing to these conditions.

Since, at the time of your telephone request to Mr. Steve Dubetz I understand that you had an imminent deadline to meet, you may have already submitted your thesis and/or report to the Alberta Environmental Research Trust. If so, I trust that you will now take appropriate steps to conform to our policy requirements.

We are pleased to know that these unpublished Research Station data and your research in cooperation with our Soil Science Section have proved useful in your Master's degree program. I trust you will find that the conditions we have specified are reasonable. I am sure that Dr. D. C. MacKay and other members of the Soil Science Section will be interested in reading your thesis and report.

Yours truly,

D. B. Wilson
Acting Director

Canada

TGA:lk

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR JAMES MICHAEL BYRNE

TITLE OF THESIS **COMPUTER ASSISTED IRRIGATION WATER MANAGEMENT**

DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE IN WATER RESOURCES

YEAR THIS DEGREE GRANTED SPRING, 1983

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **COMPUTER ASSISTED IRRIGATION WATER MANAGEMENT** submitted by JAMES MICHAEL BYRNE in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE IN WATER RESOURCES.

.....
Supervisor

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.....

Date....83..03..10.....

For Christian

ABSTRACT

Efficient utilization of a water supply is contingent upon a quantitative management criteria. Current irrigation water supply management in Alberta is qualitative or intuitive in nature. Therefore, it is not unexpected that irrigation efficiency levels are reported to be low.

The objective of this study is to demonstrate a computer assisted management approach that would quantify farm and district irrigation water management. The accepted concepts of crop irrigation scheduling and district operation to meet crop demand are applied to a test area with the TIMS (Total Irrigation Management Services) computer program. The comparison of TIMS output to the actual water use in the test area was positive in terms of water conservation and peak demand reduction.

The flexibility of a computer assisted management system is demonstrated. Management criteria can be tested under a variety of conditions, and be manipulated within safe guidelines to lower peak demands and allow for the crop utilization of most precipitation.

The information to calibrate the TIMS model for southern Alberta is compiled. Tims has been rewritten in a language compatible with IBM computer systems.

ACKNOWLEDGEMENTS

The author will always be grateful to Dr. J. P. Verschuren for his guidance and personal support.

Gratitude is extended to the Agriculture Canada Research Station, Lethbridge, and to Mr. E. H. Hobbs for access to the crop coefficient data of Messeurs Hobbs and Krogman. The cooperation of the Soil Science Section in the setup of the study area and data collection process is gratefully acknowledged. A special thank you is conveyed to Dr. M. Oosterveld for his assistance in initiating the study; and to Mr. D. P. Graham for his help with data collection and interpretation.

The patience and good humor of Mr. Alf Lagler will never be forgotten.

The cooperation of the Lethbridge Northern Irrigation District staff was much appreciated; as was that of the farmers within the study area.

The funding provided by the Alberta Environmental Research Trust is gratefully acknowledged.

This study could not have been completed without the support and patience of my wife, Cheryl.

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1. ALBERTA IRRIGATION APPROACHES

1.1 Introduction and Study Scope

A supply of clean fresh water is a necessary requirement to everyday life. However, water consuming industries have discovered in recent years that their water supplies are often over-allocated. Irrigation farming, a major water consuming industry, has been practiced since the time of the earliest civilizations. However, in the twentieth century, new technology has allowed the development of irrigation to spread over large areas, with water being transferred hundreds of miles. Inevitably, wide scale expansion has put a strain on available supplies of water. In North America, it can be observed with almost no exceptions, that every area to establish irrigation has expanded the system until the original source of water is fully utilized in every year, and often insufficient in heavy demand years. This is the present situation in southern Alberta. Expansion of irrigation to new land has strained the ability of some irrigation districts to fulfill peak water requirements. However, several studies (Hobbs, et.al., 1963; Stanley Engineering, 1978; ECA Oldman Basin Report, 1979; and many others) have indicated that the problem is not purely due to supply shortfalls but that ineffective management of the system and the supply causes major quantities of water to be lost.

This report will demonstrate how irrigation scheduling technology can be applied to optimize water supply utilization, effectively creating a greater volume of water for irrigation application through conservation. Application of the technology to large areas can be effectively achieved with computer methods.

1.2 District and Farm Efficiency Factors

Stanley/SLN Engineering (1978) defined the Irrigation Efficiency as the ratio of water beneficially utilized (by plants, for salt balance maintenance and for soil evaporation) to the total volume of water diverted for irrigation purposes. Stanley indicated the efficiency level in the Oldman River Basin from 1968 to 1974 was 31 percent. Conversely, 69 percent of the total volume diverted was lost to one of the following:

1). Reservoir losses - in most cases, the major reservoir loss factor is evaporation. However, local conditions such as outcrops of permeable strata below the full supply elevation can also result in major storage losses. Manz and Verschuren (1982) defined reservoir storage efficiency Er as

$$Er = (Vbc,r + Vst,r)/ Vu,r \qquad 1.1$$

where: Vbc,r is the volume of water delivered from the reservoir for irrigation purposes during time t; Vst,r is the change in reservoir storage during time t; and Vu,r is

the reservoir inflow during time t. The Vst,r term groups all loss factors into a single variable.

Reservoir losses are difficult to reduce. Limited evaporation suppression has been achieved with monomolecular films, but wind levels in southern Alberta would make such an application impractical.

2). Conveyance System Losses - there are two major loss factors: seepage and return flow. Some studies (Ploss et al, 1979) have indicated that significant return flow volumes are not a problem since the spill water can be beneficially utilized downstream. This study disagrees. Diversion of major quantities of water through a conveyance system, to simply be returned to streamflow, is inefficient in terms of required system capacity and maintenance. Further, seepage levels will be higher because of the excess flow (the discussion below supports this view). Greater seepage quantities will only result in compounded seepage related problems.

(a). Seepage losses are a function of the soil texture and the level of distribution system maintenance. However, for a given reach, the total volume of seepage water can be reduced if the discharge is maintained at the minimum volume required to meet immediate demands. Water savings is not the only pressing reason for reducing seepage losses. The lethal effect of salt buildup in seepage discharge areas is well documented, and readily acknowledged as a serious problem in irrigated agriculture. (Hansen et al. 1980 and others)

The volume of water lost to seepage each year can be quantified in an approximate manner using diversion and return flow data (Robinson, 1978) and the latest efficiency reports (ECA Report, 1979). The gross diversion for 7 districts in southern Alberta (Eastern, Western, Bow River, St. Mary, Lethbridge Northern, United and Mountain View-Leavitt) in 1977 was 214,099 hectare metres (1,735,000 acre feet) of water. The delivery efficiency for that year was 64 percent (ECA Report delivery efficiency is defined as the ratio of water delivered to the farmers to the total volume diverted). Hence, conveyance losses, including return flow, were (100 - 64) percent. The total return flow volume was 43612 ha.m. (353,420 acre feet); therefore, the seepage loss volume Vsl was approximately

$$Vsl = 0.36\ (214099) - 43612 = 33464 \text{ ha.m.} \qquad 1.2$$

This quantity is 15.6 percent of the total diversion.

Some fraction of the seepage loss can be attributed to phreatophytic plants. Heavy phreatophyte growth in and around a canal will not only transpire significant water volumes, but will also increase the frictional surface acting on the water; flow velocities drop, the canal wetted perimeter rises and the seepage loss increases proportionately.

(b). Return Flow - Aspects of return flow previously discussed include system capacity and maintenance problems,

and higher seepage potential with the increased flow levels. Elimination of return flow is probably not feasible in economic terms. However, efficient system design and operation can aid in reducing return flow levels to quantities that would not be significant in comparison to the total diversion. In 1977, return flow was only 9 percent of the LNID diversion. This low value reflects a concerted conservation effort due to supply problems that year. With management approaches similar to those utilized in this study, return flow ratios would fall to levels well below the 1977 Lethbridge Northern level.

Of the total volume of water diverted in an average year, about 38 percent is lost on-farm (Stanley Associates, 1978). Put in other terms, of the total volume of water delivered to the farms, 51 percent is lost in some way. The major contributors to on-farm losses are:

1) evaporation - during application, from 5 to 15 percent of the water applied can be evaporated - evaporation rises with increased temperature and wind speed. Further, an 'oasis effect' , with the sprinkler line or flooded area representing the oasis, is unavoidable.

2) run-off - this can be significant if the application rate is higher than the infiltration capacity of the soil, or when the slope of the land is great enough to encourage runoff. Runoff losses are highly variable.

3) deep percolation - the loss of water to the groundwater system - this can only occur to excess as a result of over

irrigation. For example, when soil profile can only store 15 centimetres of water, and 20 centimetres are applied, then much of the remaining 5 centimeters will percolate down to the water table.

Evaporation losses are difficult, if not impossible, to control. Different application approaches can be adopted that lower evaporation. However, run-off and deep percolation of water can be lowered to very small amounts by a scientific approach to application. Field scheduling maintains a soil moisture budget. The total storage capability of the crop root zone is determined. The daily evaporation and transpiration amounts are subtracted from the stored soil moisture, until such time as the moisture level reaches a set allowable depletion. The difference between the moisture in the soil at the full storage level and the allowable depletion level, divided by an application efficiency, is the amount of water to be applied. To illustrate: say a soil profile can store 20 centimetres of water at full storage level. With a crop evapotranspiration rate of 5 millimetres of water per day, in 20 days the moisture remaining in the soil profile is 10 centimetres. If this is the set allowable depletion, then the total amount of water to apply to the crop is

$$I=(20-10)/0.80 \qquad (1.3)$$

where 0.80 = the application efficiency.

Most farmers today do not utilize a quantitative approach in scheduling irrigation applications. Consequently, crops are either under or over irrigated; wastage of water, energy and labor or reduction in crop yields is the end result. The following case illustrates how inefficient a 'perception approach' to irrigation can be. The author was involved in a project to monitor the water use of a barley crop planted in late July . Although heavy rains had fallen on the field ten days prior to planting, the farmer still irrigated heavily shortly after planting. In late August, when installed monitoring equipment indicated high soil moisture, and a water table at less than 90 centimetres in low areas, a second irrigation was applied. Discussion with the farmer indicated the second irrigation was applied due to yellowing of the plants in the lower areas. He felt this indicated a lack of moisture, where in fact the crop stress was obviously due to a soil water glut. A field scheduling program would have resulted in less water being applied to this field.

The advantages discussed in the preceeding paragraghs can best be applied to very large areas with the help of high speed computers. This study is a demonstration of such an approach. The TIMS computer program (Total Irrigation Management Services - Bucheim et.al., 1980) is the model applied. TIMS utilizes daily climatic and district operations data to produce schedules for efficient operation of an irrigation district. These schedules will be compared

to operations during the 1981 irrigation season to demonstrate the possibility of water conservation with computer management of an irrigation district.

2. LITERATURE REVIEW

2.1 Introduction

Hobbs and Krogman (1968) describe the management of irrigation water in the field as an art - the proficiency of management depends on the skill of the artist. As with any group of individuals practicing the same art, varying levels of proficiency are developed. However, if the 'art' is replaced with a scientific approach to irrigation, the net benefits from a given quantity of water can be maximized.

In the 1970s, research into scientific methods to apply to irrigation practices was widespread. (Bucheim and Ploss, 1977; Campbell, Bucheim and Brower, 1975; Hobbs and Krogman, 1968; 1978; Jensen and Wright, 1978, and many others). Investigations into the scheduling of irrigation to meet crop demands established the multiple benefits of such a program. Logical progression of thought led to the development of the district scheduling concept, as both a complimentary program to crop scheduling, and as a means within itself to increase utilization of the water supply through careful management. Combining the two programs into a total management approach for an irrigated area is a logical measure.

2.2 Crop Scheduling Concepts

2.2.1 Soil-water-plant relationships

The ability of the soil profile to act as a water storage reservoir is well understood. Intake rates and storage capacities of the different soil types are highly variable. Texture, porosity and the chemical constituents of the soil all have a bearing on these properties. At full or field capacity, the soil profile is maintaining all the moisture it can against the force of gravity. At the opposite end of the scale is the wilting point, at which virtually all water available to the crop has been withdrawn. The quantity between field capacity and wilting point is that which is available for evapotranspiration. Depending on the soil type, this quantity may range from 7 to 25 centimetres per metre of soil (Hansen et al. 1980).

Plants draw upon the soil water solution for two main reasons: the only source of 'food' available to the plant is the dissolved nutrients in the soil solution. With ample water, large amounts of nutrients can be withdrawn from the soil, and growth occurs at peak rates. Further, at times when the climatic conditions could cause damage by overheating, water taken from the soil is transpired to aid in cooling plant tissue, thus avoiding the overheating. During a time of inadequate moisture, neither of these processes can continue at the most efficient level. An irrigation application will alleviate these problems but if

it is not well timed and of the proper amount, new problems are created to replace the old. If too little water is applied, then the time between the current and future irrigation is less than the optimum. A portion of the labor and other costs of the application are wasted. With an over-application, the soil profile is saturated, depriving the soil of oxygen, and leaching valuable nutrients out of reach of the crop roots. Thus the crop stress is not relieved but rather replaced for the time period it takes to drain the soil profile. Combining this factor with the loss of nutrients (often expensive commercial fertilizers) and the obvious waste of water illustrates that such an irrigation is not nearly as beneficial as it could be.

2.2.2 Scheduling irrigation to crop requirements

Given the above discussion, the practicality of scheduling irrigation to meet crop demands is apparent. The problem is that application of this principle can be exceedingly complex. Laboratory determination of the soil moisture level at any time does not lend itself to accurate extrapolation over large areas. Even the most efficient methods of physically determining moisture depletion levels would involve high labor and equipment costs to cover a major tract of land like an irrigation district. One obvious method that could make such large scale projects feasible is computer simulation of the soil moisture budgets, and irrigation prediction based upon the simulated values.

Simulation of evapotranspiration in maintaining soil moisture budgets has been refined to a high degree of confidence for periods of 30 days or more (Jensen and Wright, 1978; Wright and Jensen, 1978). Given these developments, computerized scheduling of major irrigation districts is practical, and offers an inexpensive approach to optimizing water supply usage. Labor involvement can be cut to a minimum since specific fields will not require moisture level monitoring more than once monthly. This compares favorably to the present approach in southern Alberta where technical staff make weekly visits to fields under scheduling programs.

2.2.3 Field scheduling benefits

Some of the benefits that can be derived from field scheduling were discussed above. However, other worthwhile advantages deserve attention.

(a). Prevention of plant stress is of high priority. By avoiding plant stress due to insufficient or excessive moisture, yields (in terms of quantity and quality) can be improved since the crop growth is always at its most efficient.

(b). The fact that no excess water is applied alleviates deep percolation, in so doing reducing the salinity problems that can accompany a raised water table. Such a development would be welcome since large areas of southern Alberta have already been adversely affected by soil salinity buildup

(Environment Council of Alberta, 1979). [1]

(c). Leaching of plant nutrients, including commercial fertilizers is prevented, so that crops will receive the full benefit of soil fertility. The possibility of local groundwater pollution with chemical fertilizers will be lessened. Add to the above the reduced chance of soil erosion due to runoff and advantages gained in terms of optimal application system usage, and the attraction of a field scheduling program becomes apparent.

2.3 Scheduling District Operations to Meet Crop Demands

2.3.1 Current operational methods

Scheduling of irrigation district operations is also a concept that requires quite elaborate methods to apply. Prediction of the water demand days or even weeks into the future is difficult without set guidelines to aid in the estimates. Most systems today maintain some degree of system scheduling; watermasters maintain main canals at flow they intuitively feel will be required. Ditchriders distribute flows down laterals and sublaterals according to their own intuition. However, concern over not having adequate supplies at critical delivery points leads to liberal estimates of the demands - a safety factor is included in each discharge. Consequently, significant amounts of water

---

[1] A good portion of this problem is directly attributable to conveyance water seepage. But over application of irrigation water with the resulting local water table rise has added to the problem significantly

are removed from storage reservoirs, and lost as return flow.

2.3.2 System Operation to meet Farm Schedules

As with on-farm scheduling, major benefits can be derived from a quantitative approach to the district scheduling process. The method of quantification is straight forward.

(a). The crop schedules produced by the evapotranspiration simulation routines are utilized as input. The daily requirements as calculated for the farms serviced by a lateral are compiled into total flows required for that lateral. The same approach is taken with each lateral within the system.

(b). Flow in the main distribution canals is determined as the summated needs of the laterals that branch off each main.

(c). The total amount of water required to meet the main canal demands is the volume that must be diverted or released from supply sources.

Obviously, the conveyance efficiency of each portion of the system is taken into account when determining requirements at that level.

A typical irrigation district can have deliveries numbering in the hundreds, if not thousands. Calculations from the turnout points back through the system to the headworks is only practical with a high speed computer. In

the process, the computer can produce system schedules for all the distribution levels that indicate to operations staff the discharge levels for each main, lateral, sublateral and turnout. Guesswork is eliminated, and water supplies will be distributed at a high level of efficiency.

The primary aim of an irrigation scheduling system is to optimize the water supply usage. Computer applications can allow large areas to be efficiently handled. In effect, it provides a management approach that reduces unnecessary diversions, minimizes operational losses and spills, and generally operates the district in an orderly, systematic manner(Bucheim et.al. 1979).

2.4 Integrating Irrigation Management

The discussion to this point has been rather general. In previous sections , references were made to the difficulties of applying field and district scheduling concepts over large areas. The question is what difficulties arise and how can they be dealt with, if at all? The integration of farm and system scheduling involves two management levels: the districts and the individual farmers. Improvements in water use efficiency can be forseen for both. However, attempting to apply a farm-district scheduling program entails maintaining soil moisture budgets for each field in the district. These numerical black holes can be easily handled by todays high speed computers. However, this involves simulation routines that can

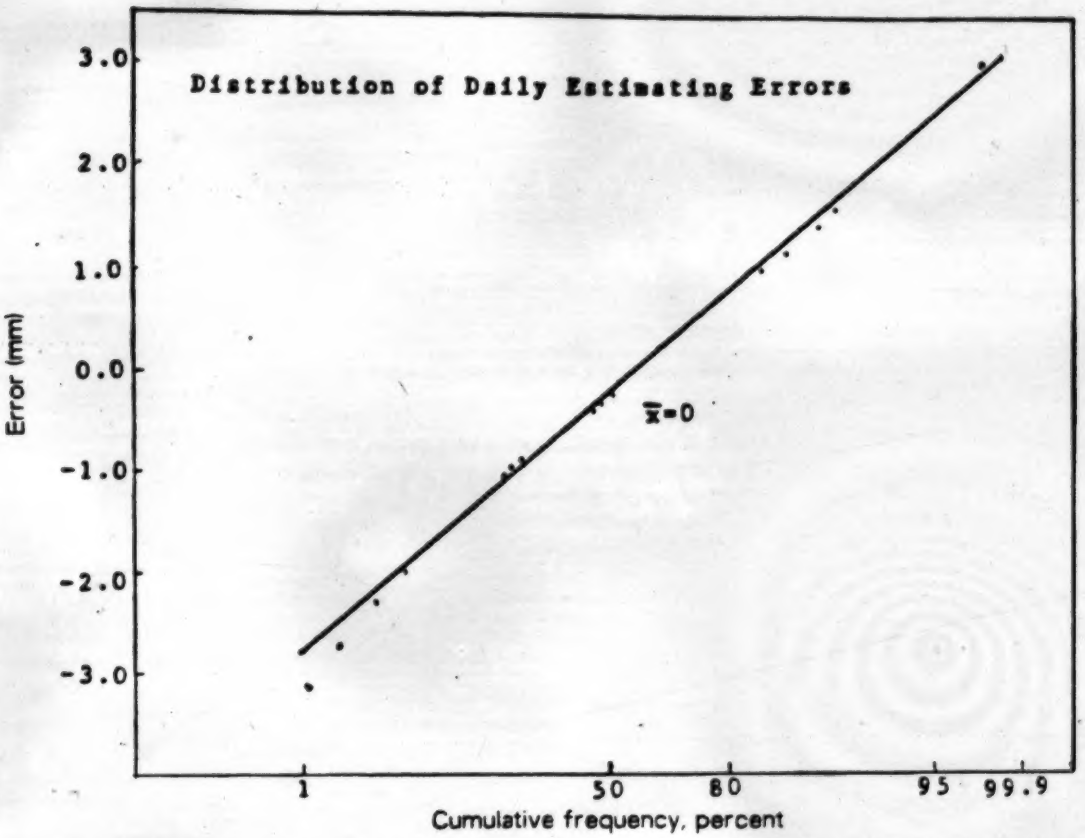

Figure 2-1 Distribution of daily errors in estimated evapotranspiration compared to measured ET (source: Jensen and Wright, 1978).

n	error	cumulative error
days	mm/day	mm.
4	0.5	2.0
9	0.33	3.0
25	0.2	5.0

95% confidence levels

Table 2-1 Relative and cumulative errors associated with prediction of soil moisture depletion for various time periods (Jensen and Wright, 1978).

confidently predict the soil moisture levels for periods in excess of the standard irrigation periods. Jensen and Wright (1978) compared the daily evapotranspiration calculated with a climatic based equation to measured ET levels (determined with weighing lysimeters) for 243 days from 1968 to 1971. They discovered the error in the simulated value could be quite large on any one day. But they also observed that the cumulative error over a number of days becomes smaller relative to the cumulative ET. Figure 2-1 illustrates why. Statistical analysis of the daily errors in simulated ET reveals the error distribution is normal about a mean of 0. The implications to a soil moisture simulation routine are discussed with reference to Table 2-1. For short periods, such as 4 days, the relative error per day is 0.5 millimetres, amounting to a cumulative error of 2.0 millimetres. However, as the number of days is increased, the relative error decreases, so the cumulative error becomes lower on a relative scale. For a period of 25 days, the cumulative error is only $\pm$ 5 millimetres, which is insignificant when application totals are in the 80 to 140 millimetre range. Essentially then, the utilization of a climatic based ET simulation routine to maintain soil moisture budgets is not useful in the short term (< 5 days), but is useful in for the longer time period (>10 days) since the relative error in the cumulative ET determination becomes insignificant.

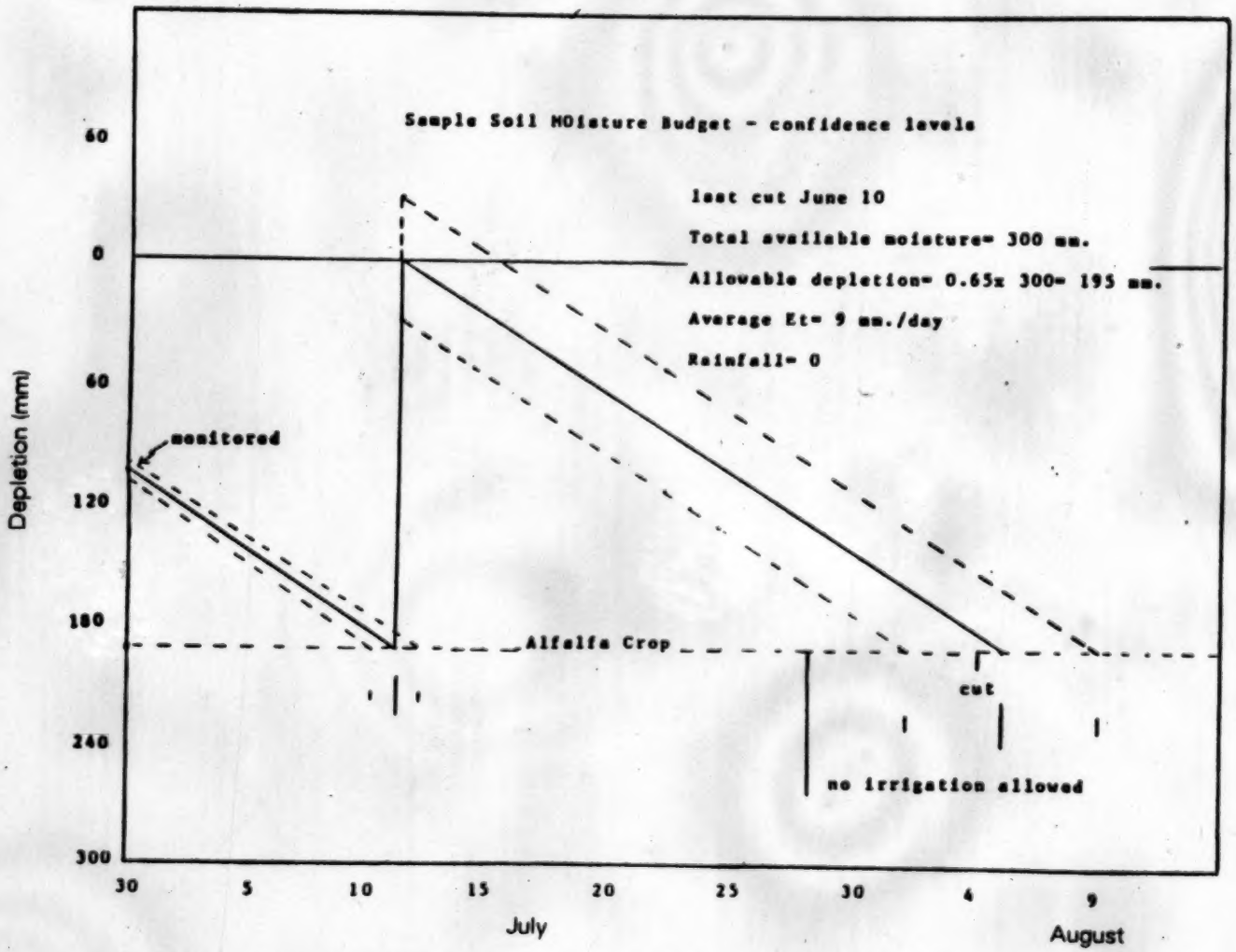

Figure 2-2 Confidence band variation associated with irrigation applications (source: Jensen and Wright, 1978).

Although the above indicates the application of a soil moisture budget simulation routine should be straight forward, field trials have often reported wide variations in the predicted and measured moisture levels after some time period. Figure 2-2 is a sample soil moisture budget (Jensen and Wright, 1978) that indicates at least one reason for the discrepancies. The budget is for an alfalfa crop for the time period June 30th to August 5th. Moisture levels were monitored on June 30th, and from that date until July 11, the predicted moisture levels had a high level of confidence as indicated by the close fit of the dashed and solid lines in the figure. On that date, an irrigation was applied, and the problem this creates is immediately obvious. Measurement of the water applied was not accurate, and the confidence band reflects this. Since the application amount is a model input, and considering the low confidence level in the value of that input, it is obvious that the confidence band of the prediction will be much wider from July 11th on. Inspection of Figure 2-2 illustrates. The confidence band shows a dramatic widening corresponding to the irrigation application. In effect, this indicates the net irrigation applied creates most of the uncertainty in maintaining the soil moisture budget. Reducing this effect will not be that difficult. Improvements in application methods and equipment should increase on-farm water management efficiency rates in the near future.

3. THE CONTROL AREA

A portion of the Lethbridge Northern Irrigation District was established as a control area for data collection on operations procedures and water consumption. Some of the data collected was used as TIMS input. Operations procedures were closely recorded; volume of water applied to each crop was only one of the parameters involved. The area formed an integral part of this study since by comparison of the computer simulations to the operations within the area the central hypothesis - A net water saving can be achieved through computer scheduling of irrigation was tested.

3.1 Location

The study area is located approximately 15 kilometres north of the city of Lethbridge. Park Lake, a small reservoir lying immediately to the west, (see Figure 6-1)is the nearest water supply link. Borders for the area were easily defined since any land that was irrigated with water from the Park Lake East lateral was included to insure the highest accuracy in the water balance determination.

The Park Lake East lateral flowing east from Park Lake is concrete lined for the first 3 kilometres (2 miles) along its route. At the road crossing just upstream of site 3 (Figure 3-3) a culvert transition feeds into an earth canal that continues generally east past site 4 and out of the study area. Along the controlled stretch, there are 8 active

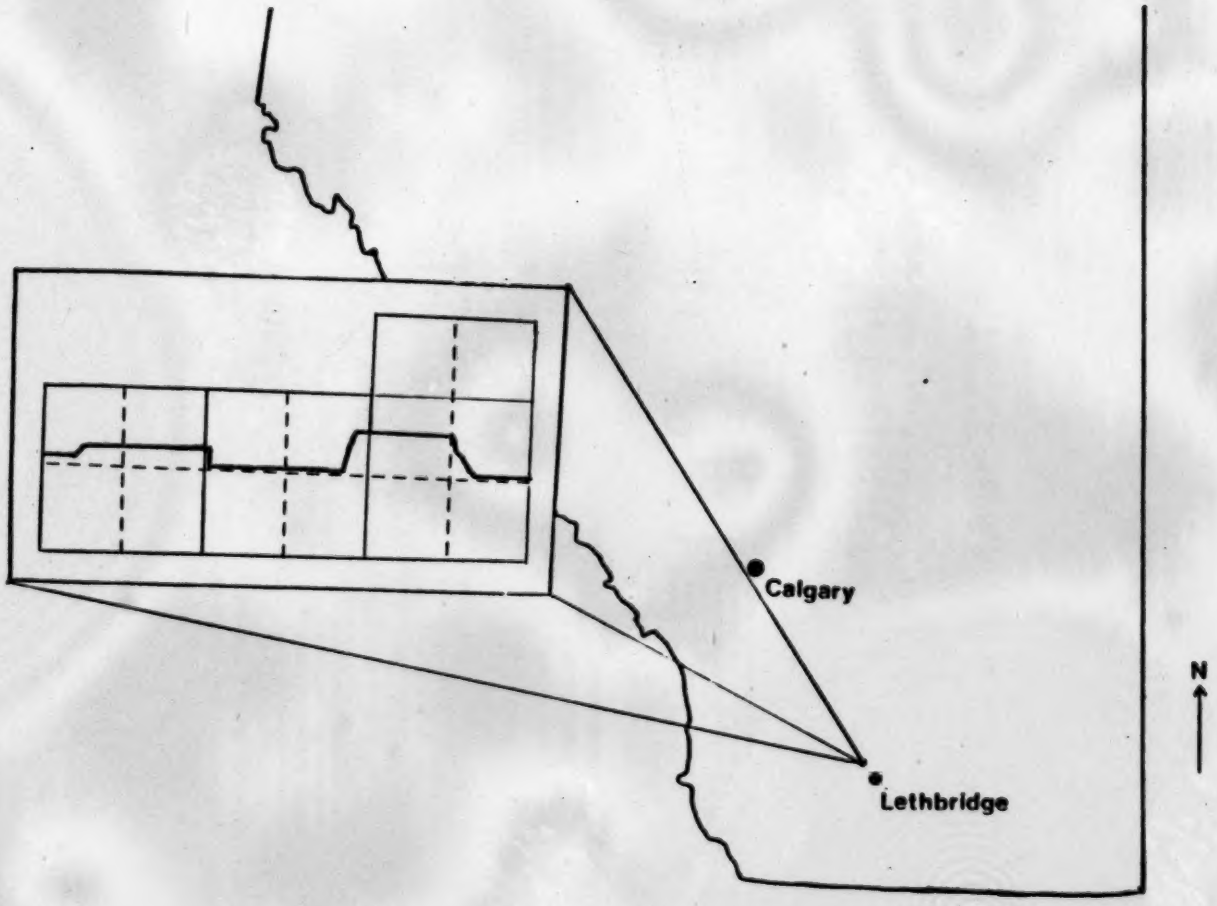

Figure 3-1 Study area location.

farm delivery points.

3.2 Surficial Geology and Soils

3.2.1 Geology

The area around Park Lake is typical high plains. A glacial till layer of up to 60 metre depths (Tokarsky, 1974) overlies generally flat lying sedimentary bedrock. A thin lacustrine veneer, associated with glacial meltwater ponding can be found over the till in the eastern sections. Slope class has been defined as gentle to very gentle - in the 2-9 percent range (Kocaoglu and Pettapiece, 1980). Some discussion indicated the western areas could be veneered with loess, but this was not confirmed by the latest published source(Kacaoglu et al, 1980).

3.2.2 Soils

3.2.2.1 Textures and Classifications

A soil class boundary runs through the eastern end of the study area as shown in Figure 3-2 (Kacaoglu et.al. 1980). To the west, genetics material types are fine loam to fine silty lacustrine and fine loamy morainal material. East of this boundary, the soils are formed of fine silt and clay lacustrine deposits.

Soil samples were taken by the author at the locations indicated in Figure 3-2. Textural analysis of the samples (hydrometer method) was carried out in

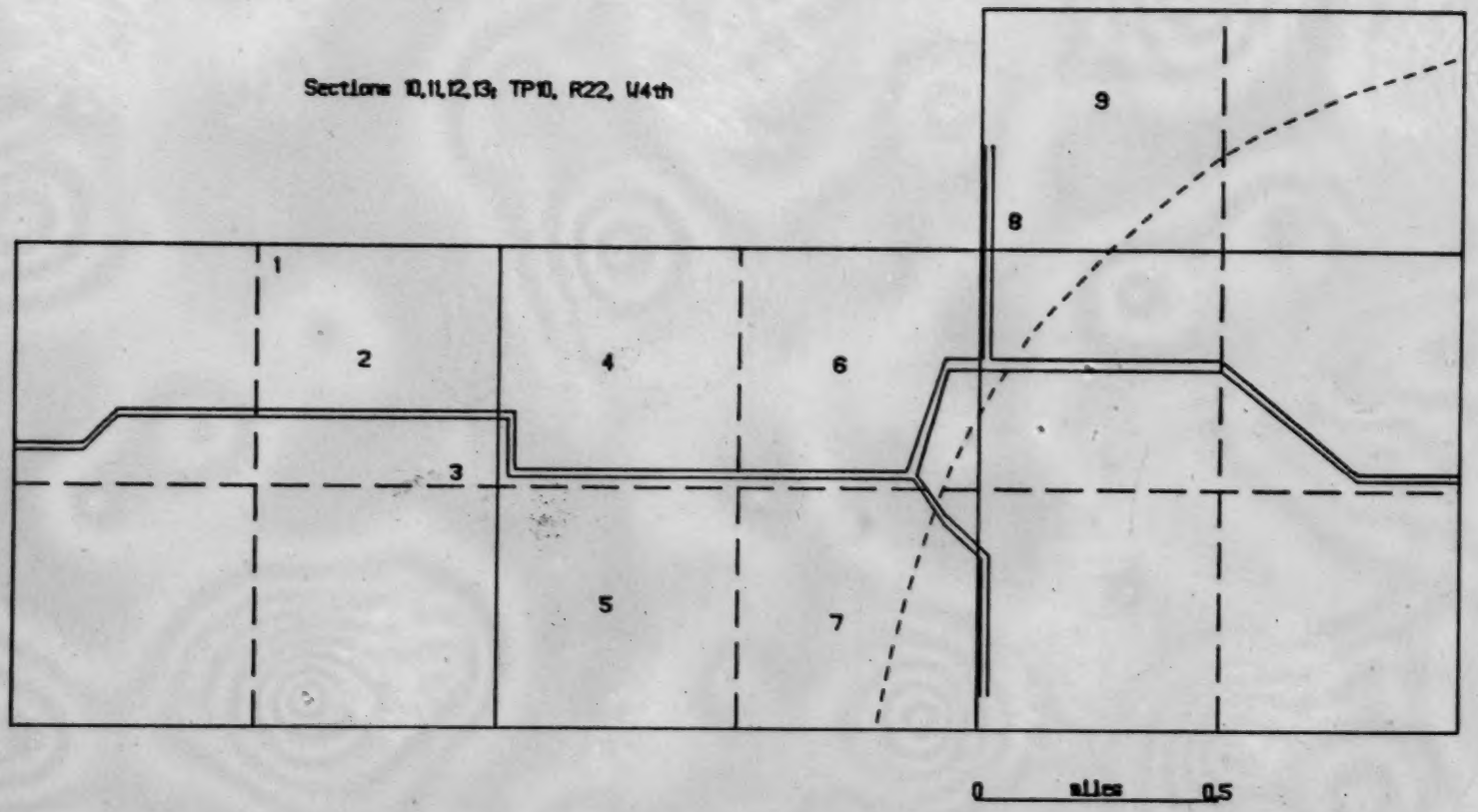

Figure 3-2 Soil sample locations. The soil data information is contained in Table 3-1.

Legal Description	Sample No.	Depth cm	% Sand	% Silt	% Clay	Classification	Avail. Moist. at Field Capacity cm
NE-10-10-22	1-1	0-15	52.1	27.9	20.0	L-ScL	20.2
	1-2	15-30	55.2	21.7	23.1	ScL	
	1-3	30-60	36.7	43.3	20.0	L-ScL	
	1-4	60-90	32.5	40.2	27.3	L	
	1-5	90-120	40.0	35.1	24.9	L	
	2-1	0-15	40.0	31.0	29.0	L-cL	20.78
	2-2	15-30	48.3	24.7	27.0	L-ScL	
	2-3	30-60	30.8	39.1	30.1	cL	
	2-4	60-90	34.9	20.9	34.2	cL	
	2-5	90-120	38.0	27.8	34.2	cL	
	3-1	0-15	33.9	25.8	28.0	L	21.06
	3-2	15-30	46.2	35.0	31.1	cL	
	3-3	30-60	40.0	33.0	27.0	L	
	3-4	60-90	31.1	41.9	27.0	L	
	3-5	90-120	31.1	44.0	24.9	L	
NW-11-10-22	4-1	0-15	40.6	31.4	28.0	L	21.47
	4-2	15-30	46.8	25.2	28.0	L	
	4-3	30-60	37.5	33.5	29.0	cL-L	
	4-4	60-90	29.3	35.5	35.2	cL	
	4-5	90-120	21.0	41.7	37.3	cL	
SW-11-10-22	5-1	0-15	45.9	31.0	23.1	L	20.76
	5-2	15-30	44.9	25.8	29.3	cL-L	
	5-3	30-60	34.6	34.0	31.4	cL	
	5-4	60-90	32.2	35.4	32.4	cL	
	5.5	90-120	36.3	34.4	29.3	cL-L	

TABLE 3-1. TEXTURAL CLASSIFICATIONS AND AVAILABLE MOISTURE FOR SOIL SAMPLES

Legal Description	Sample No.	Depth cm	% Sand	% Silt	% Clay	Classification	Avail. Moist. at Field Capacity cm
NE-11-10-22	6-1	0-15	36.3	29.2	34.5	cL	21.72
	6-2	15-30	34.2	31.3	34.5	cL	
	6-3	30-60	30.1	37.5	32.4	cL	
	6-4	60-90	26.0	41.6	32.4	cL-SicL	
	6-5	90-120	34.2	38.5	27.3	cL	
SE-11-10-22	7-1	0-15	38.7	34.0	27.3	L	22.17
	7-2	15-30	30.5	35.0	34.5	cL	
	7-3	30-60	26.3	39.2	34.5	cL	
	7-4	60-90	30.5	41.2	28.3	L-cL	
	7-5	90-120	24.3	49.5	26.2	L	
SW-13-10-22	8-1	0-15	33.9	35.0	31.1	cL	21.83
	8-2	15-30	24.6	40.2	35.2	cL	
	8-3	30-60	23.5	44.4	32.1	cL	
	8-4	60-90	29.7	43.3	27.0	L	
	8-5	90-120	27.7	47.4	24.9	L	
	9-1	0-15	36.3	35.4	28.3	L	22.41
	9-2	15-30	33.9	37.9	28.3	L	
	9-3	30-60	31.8	39.9	28.3	L	
	9-4	60-90	31.8	42.0	26.2	L	
	9-5	90-120	25.6	42.0	33.2	cL	

TABLE 3-1.(cont.) TEXTURAL CLASSIFICATIONS AND AVAILABLE MOISTURE FOR SOIL SAMPLES

Lethbridge Research Station laboratories by Mr. W. Holstein. The textural data are presented in Table 3-1. It was found that the textural data conformed to the general fining trend eastward indicated by Kacaoglu et al.

The primary reason for the textural analysis of area soil samples rested with the need to determine the water holding capacity of the soil profile. Empirical equations (Oosterveld and Chang, 1980) relating water storage capability to soil texture and depth were utilized: the method requires the textural data from the soil profile. The Oosterveld-Chang equations for calculating the soil storage capability are

$$Fc = (25.713+0.469C-0.184S-0.0329D)\ C^{0.080} \qquad (3.1)$$

$$Wp = 4.035+0.299C-0.034S-0.016D \qquad (3.2)$$

where Fc is the soil moisture in percent by weight at field capacity, Wp the equivalent wilting point, C and S are the clay and sand content of the soil in percent by weight, and D is the mean depth of the sample in centimetres.

Once Fc and Wp were calculated, then the volumetric moisture Pv, expressed as a depth, was determined in the standard manner,

$$Pv = (Fc - Wp)Pb\ d \qquad (3.3)$$

where Pb is the average bulk density of the samples (estimated as 1.45 grams/cubic centimetre) and d is the mean sample depth ie. if the sample was taken from the 60 to 90 centimetre depth, the sample depth d is 30 centimetres. The sample locations are marked in Figure 3-2. Table 3-1 contains the grain size distribution data and the total available moisture in the profile at full supply level.

3.2.2.2 Soil Chemistry

Crops are effected in 2 ways by high concentrations of dissolved salts in the soil water solution. First, as the concentrations rise, the osmotic pressure increases, effectively raising the wilting point and reducing the supply of soil moisture available. Second, specific plants are detrimentally effected to variable degrees by certain salt ions. In order to ensure neither of these problems were prevalent within the study area, the following tests were performed by the author (with the much appreciated guidance of Mr. D. Graham, LRS) on the samples taken for textural analysis. Extracts from saturation pastes were tested for pH levels and electrical conductivity. The range of pH levels was from 7.6 to 8.3, with the majority of the samples very close to 8.0. Electrical conductivity readings were well below 4.0 mmhos/cm. in most cases, although several reading

were above this value, with the highest being 6.8 (a mho is a measure of electrical conductivity. It is essentially the opposite of an ohm - the measure of electrical resistivity. As the saline content of the extract rises, so does its electrical conductance. Hence, electrical conductivity or EC, is a reasonable measure of the degree of salinity in the soil profile). Rissel (1973) indicates that if the EC of a saturation extract is less than 4.0 mmhos/cm., then no crop will be adversely affected by the soil salt. For EC levels in excess of 8.0 mmhos/cm., only salt tolerant crops can survive, and then with reduced yields. With this in mind, it is felt to be valid to neglect the saline effects in the two samples where EC levels were above 4.0. The argument to support this is threefold: first, only one field has an average EC reading over 4.0 when the entire profile is considered. That level is 5.62 mmhos/cm. Secondly, irrigation applications will prevent the soil solution from reaching concentrations where osmotic pressure will affect the soil supply. Finally, barley, a crop with a high degree of salt tolerance is the field crop in the area where EC levels are over 4.0. Given these three factors, it was felt that soil salinity levels could be neglected.

3.3 Data Collection

3.3.1 Discharge Measurement

Attempting to compare water consumption to simulations entailed the installation of accurate discharge measurement structures. These were constructed at four sites along the Park Lake East lateral, as labeled in Figure 3-3. Sites 1 and 2 are broad crested weirs of trapezoidal cross-section, located on the concrete section of the lateral. Sites 3 and 4 are sharp crested Cipoletti weirs. The weirs were situated so conveyance efficiencies could be determined for the lined and unlined reaches. However, the approach taken in the analysis circumvented the need to determine a single efficiency rating.

Two other Cipoletti weirs were installed on the small sublaterals RUST and COMN, at locations as indicated on Figure 3-3 (sites 5 and 6). These served as checks on the system. At times when the flow was 'steady', the discharge levels over all 6 weirs could be compared, and checked to ensure accuracy. The two extra weirs created a closed system, and made these checks much simpler. Since this was the only function of these weirs, constant recorders were not installed. Daily readings of the staff gages at each weir provided all the information necessary for elementary checks on the system.

3.3.1.1 Calibration of Flow Measurement Structures

In order to ensure the highest degree of accuracy, the weirs at sites 1 to 4 were calibrated during the 1980 summer. For each weir, discharge levels were measured over a wide flow range by the author and D. Graham of the Lethbridge Research Station. The same current meter was utilized for every measurement. The meter had been calibrated by the National Calibration Service, Canada Centre for Inland Waters, the previous winter. The hydraulic head level on the staff gauge at each weir was recorded for each discharge measurement. The recorded head discharge data is presented graphically in Figures 3-5 to 3-8.

Continuous hydraulic head levels were recorded in stilling wells installed just above each site. To convert the head levels to discharge, the data in Figures 3-5 through 3-8 was fitted to a function

$$Q = a\,H^{d} \qquad (3.4)$$

where Q is the discharge, H the upstream hydraulic head and a and d are regression coefficients. An attempt was made to fit the data to the conventional theoretical equation ie.

$$Q = Cd\,L\,g^{0.5}\,H^{1.5} \qquad (3.5)$$

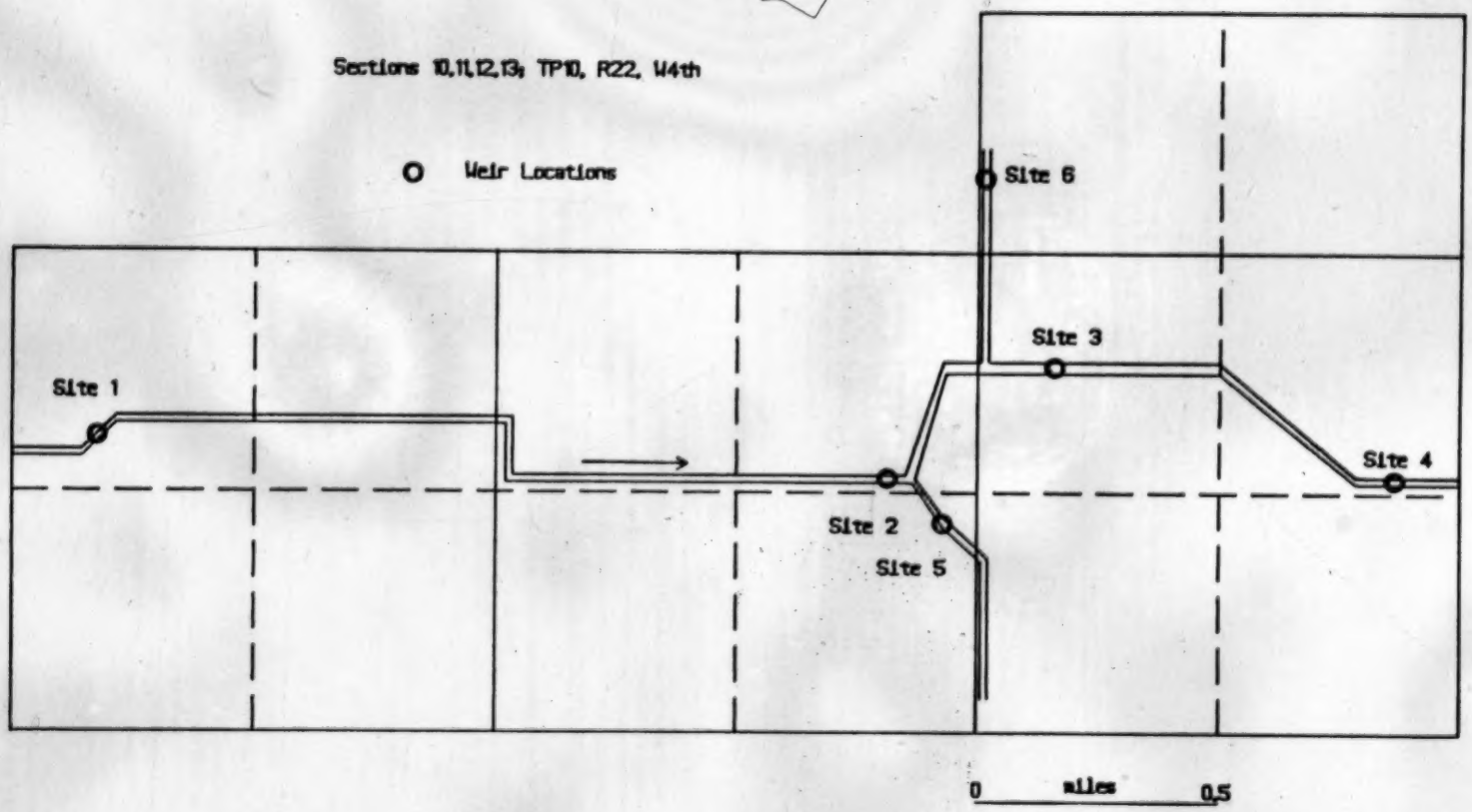

Figure 3-3 The study area. The area was established along the Park Lake East lateral of the Lethbridge Northern Irrigation District. Weir installation points are numbered with reference to the text discussion.

where Cd, L and g are a coefficient of discharge, the weir crest length and gravitational constant, respectively. However, correlations were much higher when the data was fit to equation 3.4. The discharge relations derived for sites 1 to 4 are

$$Q1 = 4.515\ H^{1.652} \tag{3.6}$$

$$Q2 = 4.2826\ H^{1.7083} \tag{3.7}$$

$$Q3 = 2.2166\ H^{1.6563} \tag{3.8}$$

$$Q4 = 2.704\ H^{1.787} \tag{3.9}$$

These relationships were utilized to calculate, from the stage height records, the daily flow volumes past each site. The net consumption of water between two sites could then be determined as the volume at the first minus the volume to pass the second.

3.3.1.2 Missing Flow Data

On 2 occasions, problems with the recorders resulted in the loss of head data above a weir. The periods lost were May 28th through June 4th at site 2, and June 25th to July 1st at site 3. Rather than work around these periods, the missing data was approximated. A regression equation (3-10) was fit to the discharge data between sites 1 and 2, with corrections at site 2

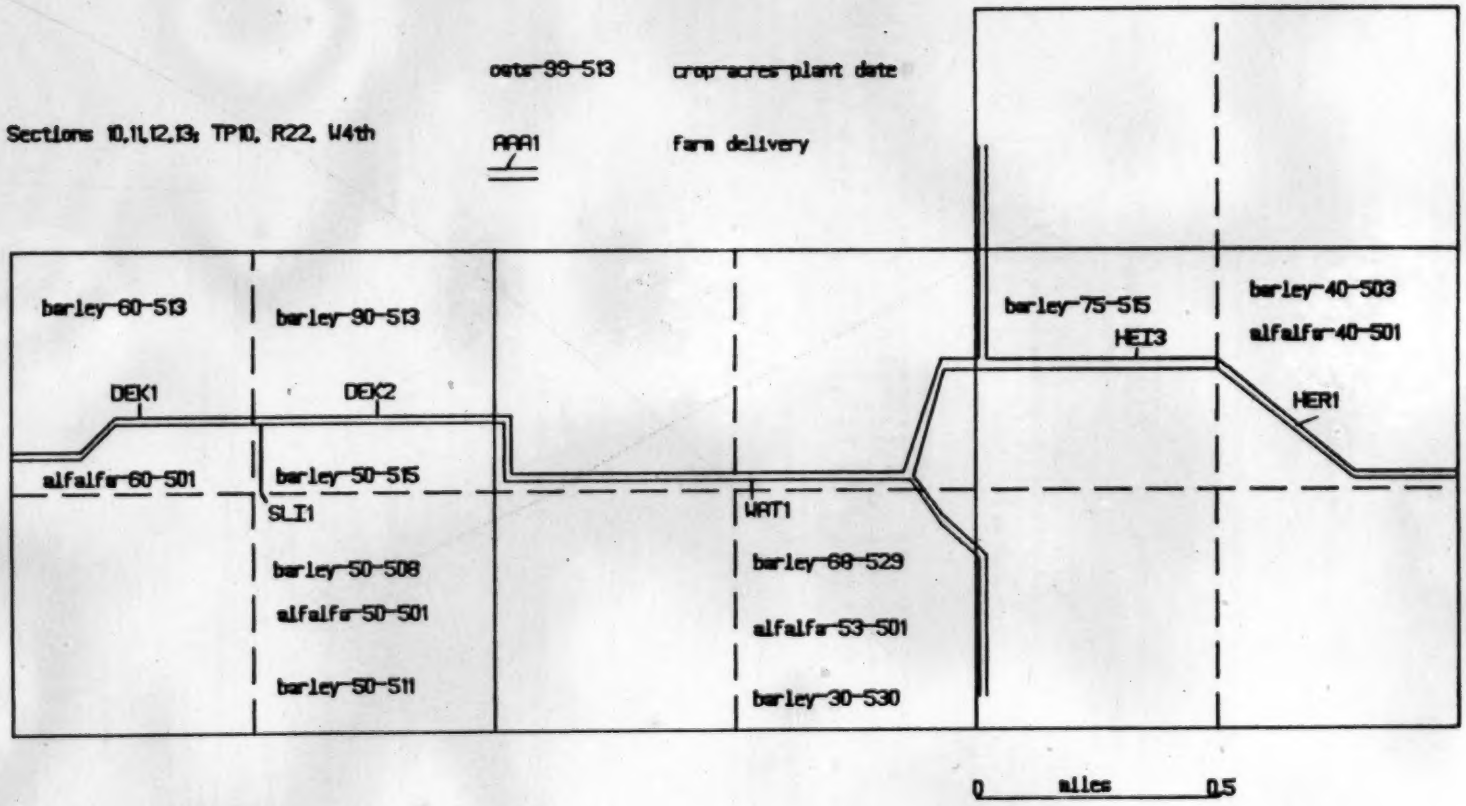

Figure 3-4 Crop data for the 1981 season. Only those areas with crop data information were irrigated in 1981.

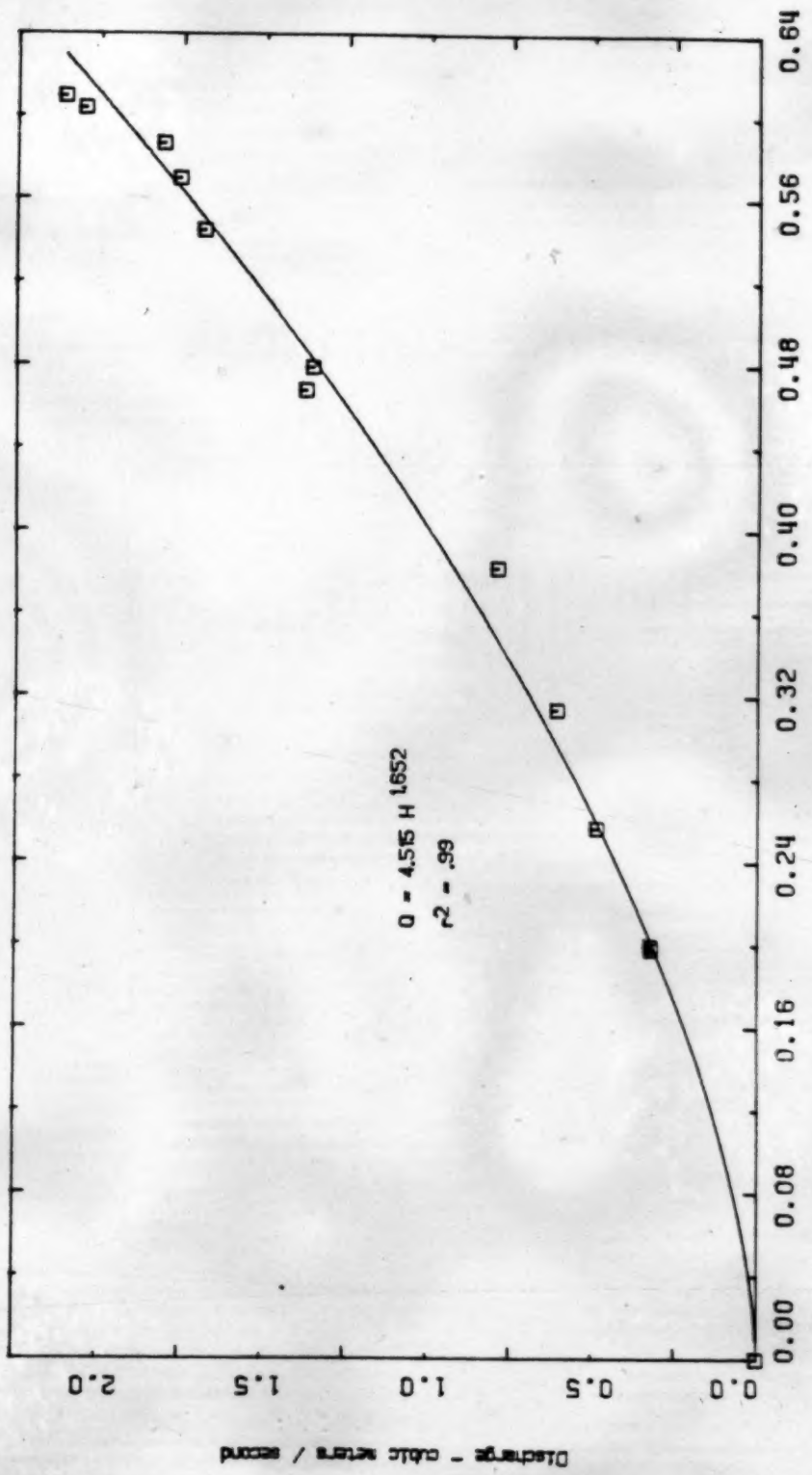

Figure 3-5 Site 1 stream guaging data and best fit curve.

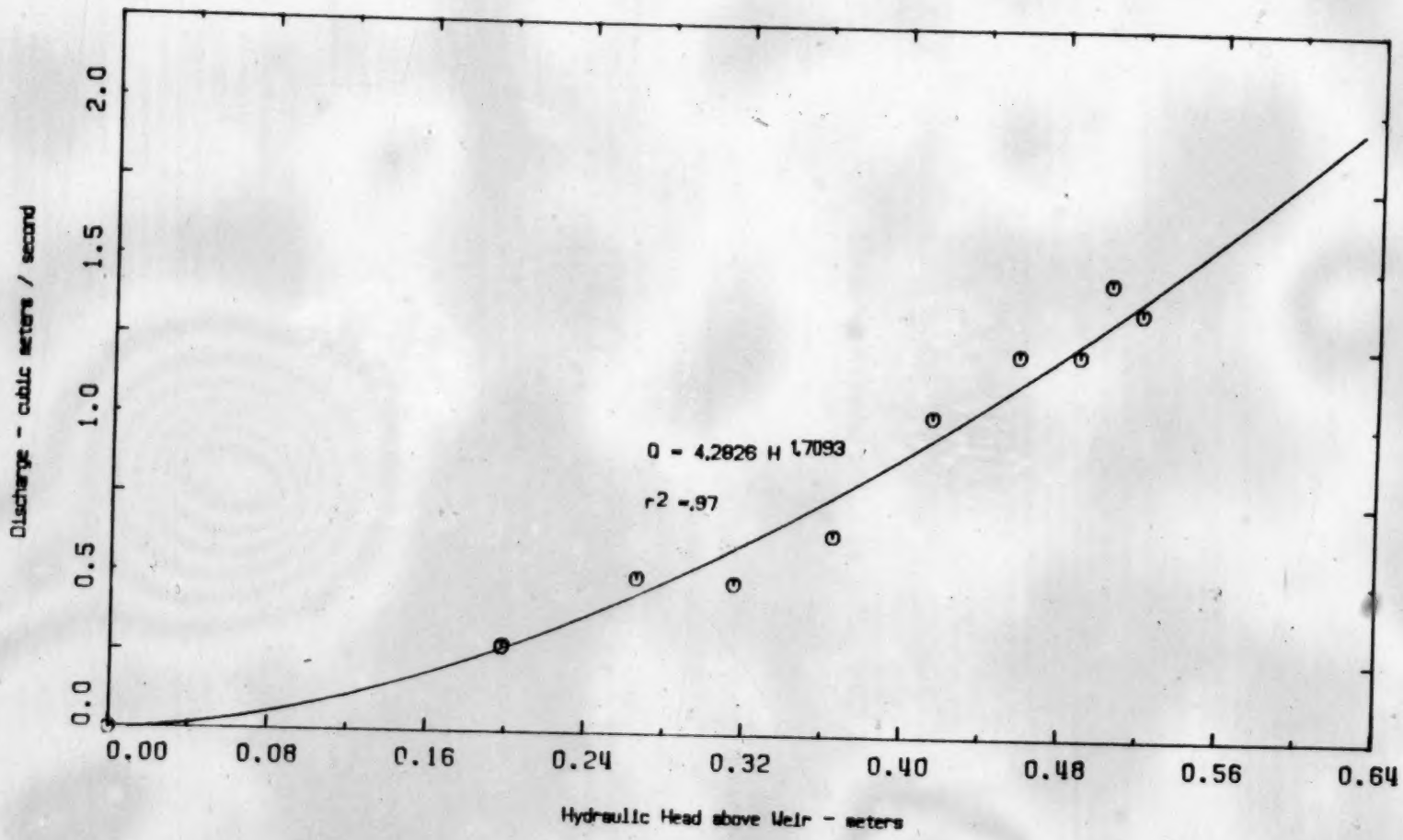

Figure 3-6 Site 2 stream guaging data and best fit curve.

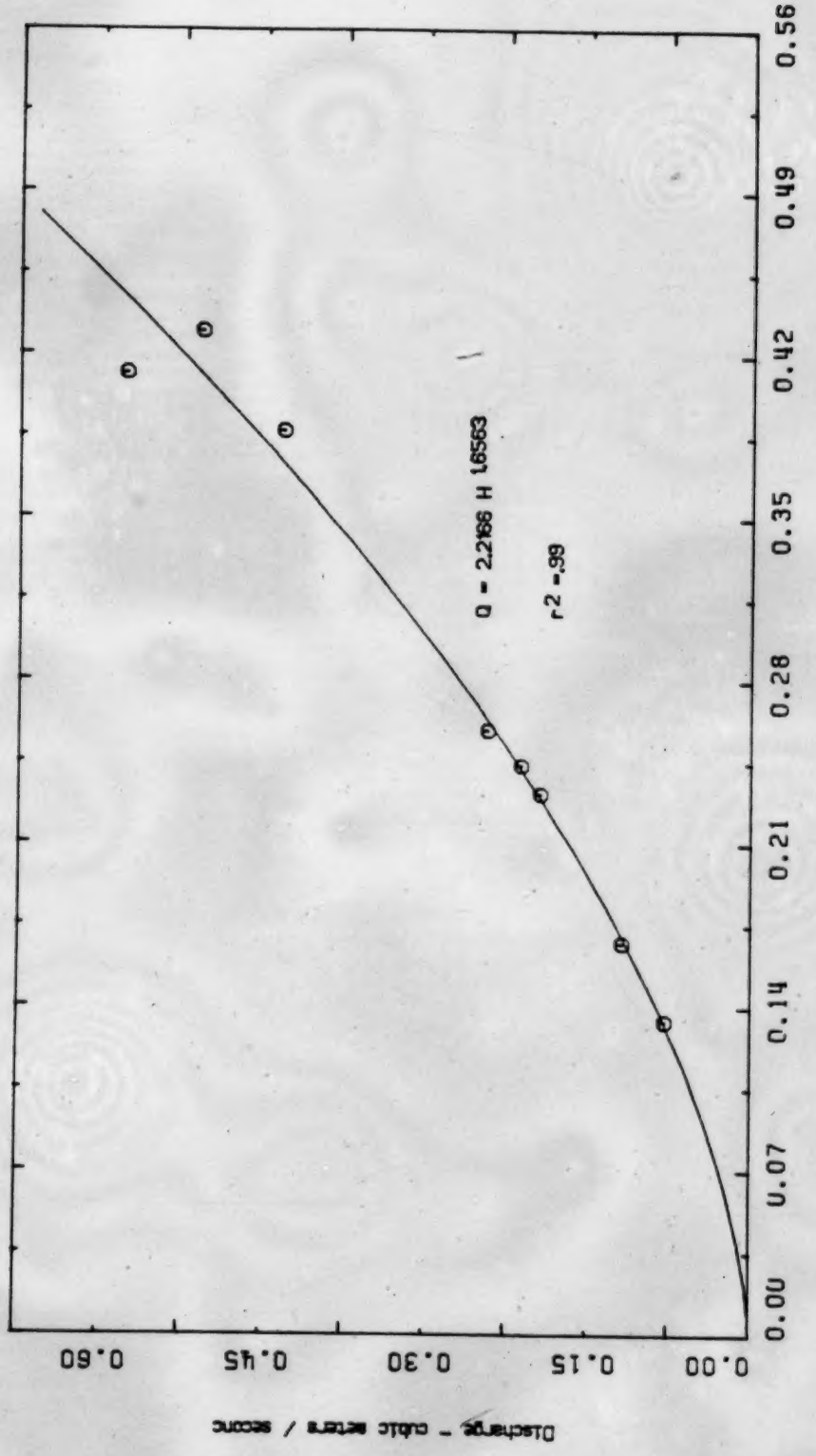

Figure 3-7 Site 3 stream guaging data and best fit curve.

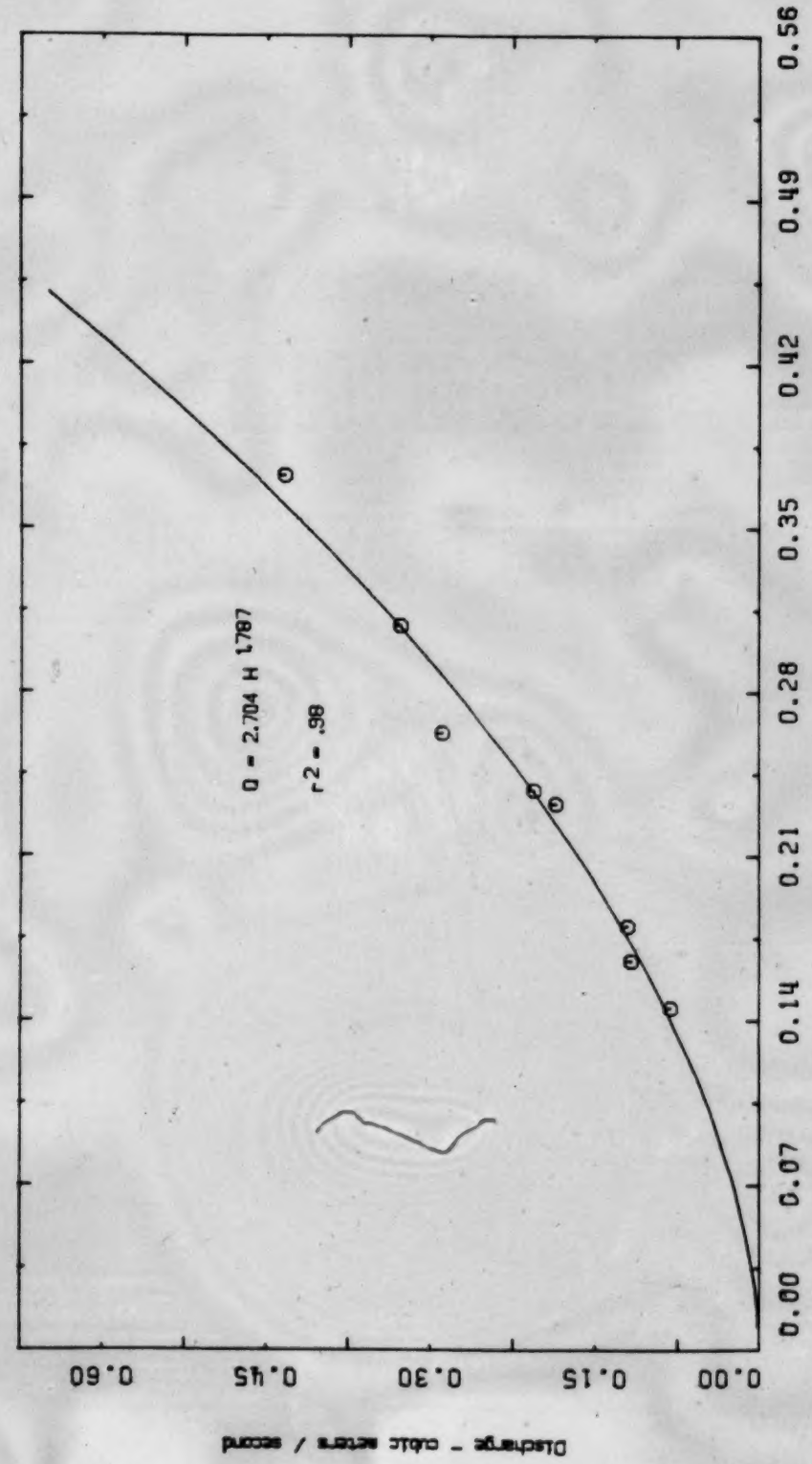

Figure 3-8 Site 4 stream guaging data and best fit curve.

to account for farm water use.

$$Q2 = 0.793\ Q1^{1.008} \qquad (3.10)$$

$r^2 = .97$

Missing data was filled in with equation 3-10.

The same approach for sites 3 and 4 utilized

$$Q3 = 273.472\ Q4^{0.481} \qquad (3.11)$$

$r^2 = .85$

to approximate the data required.

The generated data was treated as actual data in all cases.

3.3.2 Crop Data

Crop data was gathered for all fields within the study area. Three points were of primary interest:

1). crop type - the effective rate of water consumption is a function of the plant type. This is accounted for in each case. Hobbs and Krogman (1976) documented the consumptive use curves for various crops in southern Alberta.

2). plant date - evapotranspiration rates vary with the degree of crop maturity.

3). acreage - this is the third factor involved in determining volumes of water required. Thirty acres of barley will require twice as much water as 15 acres, all

other factors being equal.

The above data is utilized in TIMS in the following way. For a crop defined by type and plant date, the ET routine calculates the daily water usage. The ET routine will extend the recent evapotranspiration trends for two weeks into the future, and will indicate what crops will require irrigation to start within this time. The volume of water to deliver is determined from the set depletion, the application efficiency and the total acreage.

3.3.3 Application Rates and Daily Farm Consumption

In order to determine the rate at which water was applied to each crop, and the total volume of water applied, pump tests were carried out using a Doppler meter to measure water velocity within the farmers mainlines. With velocity data measured, determination of discharge is straight forward. Then, simple unit conversions allowed for the calculation of hourly application rate. For a discharge of 0.057 cubic metres per second, the application rate is

$$i = 0.057 \times 3600 / (800 \times 18)$$

$$i = 1.07 \text{ centimetres per hour}$$

800 x 18 is the width of area covered by a sprinkler system 800 metres long. An application efficiency of 75 percent is applied in all cases. Hansen et.al. (1980) and others have found this to be about the average application efficiency for sprinkler systems.

Daily farm consumption was also determined from the Doppler readings. For the discharge above, the daily consumption is

$V = 0.057 \times 3600. \times 24$

$= 4514.4$ cubic metres.

Most farmers only operate for 21 or 22 hours per day (depending on the time required to move the system for the next set), but water is delivered at a steady rate. The excess delivered during shut-downs is either stored in the farm reservoir or more often, spilled down an overflow ditch. In either case, the water is considered consumed since it is not returned to the system, and therefore is not available to other water users.

Tables 5-1 and 5-3 [2] contain daily water use data for the study area. These values are the summated daily consumption volumes for the farms in each area.

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[2] on pages 54 and 60, respectively

4. TOTAL IRRIGATION MANAGEMENT SERVICES PROGRAM (TIMS)

The TIMS computer program was developed at the Engineering and Research Center, United States Department of the Interior, Water and Power Resources Service. It was made available for this study through the Canada Department of Agriculture Research Station, Lethbridge.

The original TIMS language was Control Data Corporation Fortran IV (a basic language version is also available). CDC Fortran is not compatible with the University of Alberta Amdahl or the IBM Computer (CDA) systems. For this reason, major portions of TIMS were rewritten in IBM, Fortran IV by the author and Mr. A. Lagler of the Lethbridge Research Station.

4.1 Data Input

4.1.1 Interactive Input

TIMS requires a number of interactive entries that determine the amount and type of output. Figure 4.1 is a sample run for a date 714 (July 14th) , and illustrates some of the interactive sequences. A yes to any of the prompts shown will result in 1 or more subroutine calls to either alter input files or produce the required output. Interactive input generally consists of a number or letter that cannot be conveniently input through a file system. However, the input files CROPCU and LATFLD (crop consumption use & lateral field files) are built interactively at the

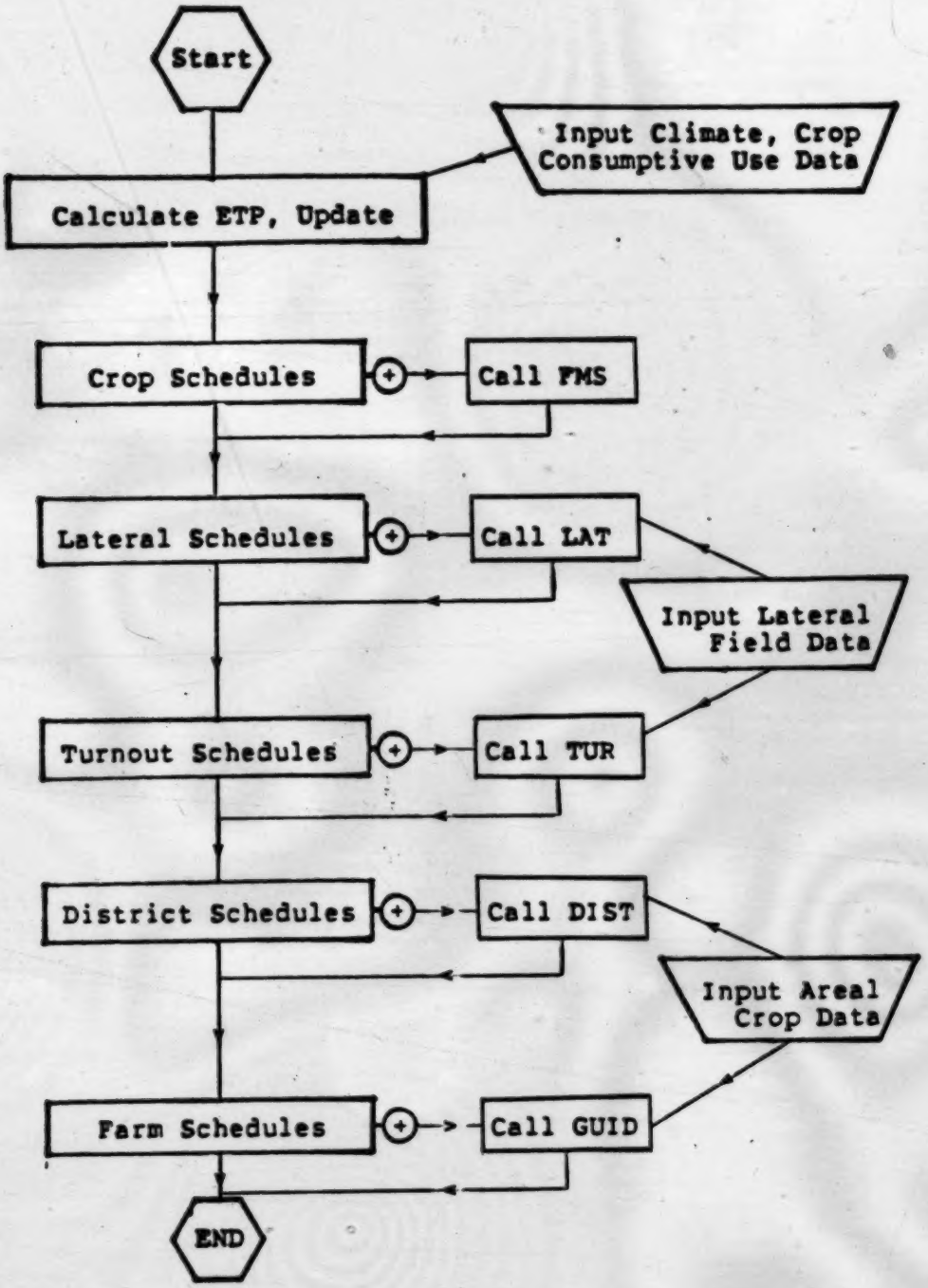

Figure 4-1 Schematic flow diagram for the TIMS model

```
# $run T.LOAD
# 15:28:14
  DO YOU HAVE BUILD/ADD/ET ADJ. CHANGES TO CROP CONS.
  USE FILE - TYPE Y OR N
  N     (altering CROPCU file with an editor is easier)

    $$ THERE ARE NO NEW DATA ON THE CLIMATE FILE
  YOU ARE MAKING A RERUN THROUGH  713 $$

  DO YOU HAVE ANY LATERAL FIELD DATA - TYPE Y OR N
  N     (Y to enter water orders - otherwise use editor)
  DO YOU WANT ALL PRINTOUTS - TYPE Y OR N
  N
  DO YOU WANT FIELDMANS SCHEDULING SHEETS - TYPE Y OR N
  Y(see inactive input below)
  DO YOU WANT TURNOUT SCHEDULES - TYPE Y OR N
  Y
  DO YOU WANT LATERAL SCHEDULES - TYPE Y OR N
  Y
  DO YOU WANT DELIVERY REQUIREMENT PRINTOUTS - TYPE Y OR N
  Y       (see interactive input below)

  ***** READY TO PRODUCE FIELDMANS SCHEDULES *****

  ENTER CROP NUMBER AND PLANTING DATES(1-4), BREAK 99,
  1,501.0.0.0,        (input)
  ENTER CROP NUMBER AND PLANTING DATES(1-4), BREAK 99,
  99,                 (input)
  $$$$ FIELDMANS SCHEDULING SHEETS ARE DONE $$$$

  $$$$$$ TURNOUT SCHEDULES ARE FINISHED $$$$$$

  $$$$$$ LATERAL SCHEDULES ARE FINISHED $$$$$$

  $$$$$$ WATER ORDER DATA IS SAVED $$$$$$


  ** READY TO PRODUCE DIST. DELIVERY SCHEDULES **


  ENTER AREA REQUIRING SCHEDULE(S)
  TO BREAK ENTER    3 BLANKS
  LNID          (input)

  ENTER AREA REQUIRING SCHEDULE(S)
  TO BREAK ENTER    3 BLANKS
              (input)
  $$$$$$ IRR. DIST. DELIVERY SCHEDULES ARE DONE $$$$$$


  ** READY TO PRODUCE FARM IRRIGATION GUIDES **

  ENTER AREA REQUIRING SCHEDULES - BREAK 3 BLANKS
  LNID          (input)
  ENTER AREA REQUIRING SCHEDULES - BREAK 3 BLANKS
              (input)
  $$$$$$ FARM IRRIGATION GUIDES ARE FINISHED $$$$$$

# 15:29:05  T=0.788  RC=0
```

Figure 4-2 Sample of TIMS model interactive run

season start, with mid-season alterations or additions being handled in the same manner.

4.1.2 Input Data Files

Four basic files provide the program interaction required. These are:

1. CLDATA - climate data file
2. CROPCU - crop consumptive use file
3. LATFLD - lateral field file
4. AREA - area wide crop patterns

4.1.2.1 Climate File

Climate input is utilized to calculate the daily potential evapotranspiration. Prior to a run, the user enters, for the dates concerned, the daily maximum and minimum temperatures (Columns 2 and 3), net solar radiation (Column 6) and any precipitation (Column 7) that has occurred. The next four values are the program generated effective rain, potential evapotranspiration, summated potential ET and the Julian date (January 1st is day 1; December 31st is day 365). The last two values are the forecast ETP values for week 1 and week 2 irrigation predictions. These values are entered interactively, as demonstrated in Figure 4.1. Zero values are entered in Columns 4 and 5, as these locations are not utilized. A sample CLDATA file is provided in Figure 4-2.

4.1.2.2 Crop Water Use Data File

CROPCU contains the data that relates each crop's rate of moisture utilization to the daily potential evapotranspiration. Wright (1981) and others have adopted the crop coefficient approach, i.e.

$$K = ETc/ETr \qquad (4.1)$$

where K is an empirical crop coefficient, ETr is some reference evapotranspiration (usually potential), and ETc is the particular crop evapotranspiration. From Equation 4.1, it follows:

$$ETc = K\ ETr \qquad (4.2)$$

If K and ETr are known, the crop moisture use determination is trivial. Hobbs (pers. comm., data in preparation) has developed 3rd degree polynomial equations for K versus the Julian date, for a number of common southern Alberta crops. Plots of his curves are included in Appendix A. These relationships are utilized to establish the CROPCU input file as shown in Figure 4-3. The file contains summations of crop ET for set increments of the reference evapotranspiration, which in this case is the Jensen - Haise potential evapotranspiration calculation.

```
  1    0.0110 19.10  125   156   162
  2      401  37.  32.   0.   0.0    113. 0.09 0.090 0.013   0.206  91 .0  .0
  3      402  41.  32.   0.   0.0    198. 0.0  0.081 0.025   0.231  92 .0  .0
  4      403  46.  30.   0.   0.0    424. 0.0  0.072 0.060   0.291  93 .0  .0
  5      404  58.  26.   0.   0.0    432. 0.0  0.063 0.074   0.365  94 .0  .0
  6      405  52.  40.   0.   0.0    518. 0.0  0.054 0.105   0.470  95 .0  .0
  7      406  37.  24.   0.   0.0    264. 0.0  0.045 0.022   0.492  96 .0  .0
  8      407  53.  28.   0.   0.0    439. 0.0  0.036 0.070   0.562  97 .0  .0
  9      408  56.  28.   0.   0.0    258. 0.02 0.047 0.044   0.606  98 .0  .0
 10      409  52.  28.   0.   0.0    539. 0.0  0.036 0.084   0.690  99 .0  .0
 11      410  66.  25.   0.   0.0    469. 0.15 0.175 0.093   0.783 100 .0  .0
 12      411  39.  33.   0.   0.0    124. 0.06 0.209 0.015   0.798 101 .0  .0
 13      412  43.  30.   0.   0.0    258. 0.0  0.186 0.033   0.831 102 .0  .0
 14      413  46.  21.   0.   0.0    392. 0.0  0.163 0.042   0.873 103 .0  .0
 15      414  34.  30.   0.   0.0    127. 0.38 0.520 0.012   0.885 104 .0  .0
 16      415  37.  30.   0.   0.0    169. 0.0  0.459 0.018   0.903 105 .0  .0
 17      416  40.  32.   0.   0.0     67. 0.50 0.898 0.008   0.911 106 .0  .0
 18      417  38.  33.   0.   0.0     97. 0.80 1.587 0.011   0.922 107 .0  .0
 19      418  44.  34.   0.   0.0    220. 0.08 1.476 0.032   0.954 108 .0  .0
 20      419  48.  32.   0.   0.0    347. 0.0  1.279 0.054   1.008 109 .0  .0
 21      420  45.  31.   0.   0.0    178. 0.10 1.182 0.025   1.033 110 .0  .0
 22      421  37.  31.   0.   0.0    118. 0.50 1.490 0.013   1.046 111 .0  .0
 23      422  49.  34.   0.   0.0    311. 0.21 1.464 0.052   1.098 112 .0  .0
 24      423  48.  35.   0.   0.0    337. 0.37 1.577 0.056   1.154 113 .0  .0
 25      424  59.  28.   0.   0.0    679. 0.0  1.283 0.125   1.279 114 .0  .0
 26      425  63.  34.   0.   0.0    494. 0.0  1.027 0.109   1.388 115 .0  .0
 27      426  66.  45.   0.   0.0    481. 0.0  0.771 0.132   1.520 116 .0  .0
 28      427  64.  44.   0.   0.0    282. 0.26 0.825 0.074   1.594 117 .0  .0
 29      428  66.  49.   0.   0.0    427. 0.0  0.673 0.124   1.718 118 .0  .0
 30      429  56.  46.   0.   0.0    283. 0.0  0.529 0.068   1.786 119 .0  .0
 31      430  62.  44.   0.   0.0    500. 0.0  0.385 0.128   1.914 120 .0  .0
 32      501  64.  46.   0.   0.0    456. 0.0  0.251 0.123   2.037 121 .0  .0
 33      502  64.  45.   0.   0.0    475. 0.08 0.247 0.127   2.164 122 .0  .0
 34      503  49.  37.   0.   0.0    318. 0.22 0.396 0.057   2.221 123 .0  .0
 35      504  43.  34.   0.   0.0    178. 0.26 0.600 0.026   2.247 124 .0  .0
 36      505  51.  36.   0.   0.0    312. 0.02 0.538 0.057   2.304 125 .0  .0
End of file
```

Figure 4-3 Sample climate file.

```
  1                          0.0   5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00 50.00
  2     ALFA 1   50. 100     0.0   4.58 10.75 16.18 21.37  0.00 00.00 00.00 00.00 00.00  0.0
  3     BARL 2   50. 100     0.0   1.79  6.9  11.93  0.0   0.0   0.0   0.0   0.0   0.0   0.0
  4     WHT  3   50. 100     0.0   1.44  5.95 11.79  0.0   0.0   0.0   0.0   0.0   0.0   0.0
  5     OATS 4   50. 100     0.0   1.55  5.96 12.10  0.0   0.0   0.0   0.0   0.0   0.0   0.0
  6     MGRN 5   50. 100     0.0   1.44  5.95 11.79  0.0   0.0   0.0   0.0   0.0   0.0   0.0
  7     SBTS 6   45. 100     0.0   1.44  4.91  9.86 14.77  0.0   0.0   0.0   0.0   0.0   0.0
  8     CORN 7   55. 100     0.0   1.04  3.28  7.46 12.13  0.0   0.0   0.0   0.0   0.0   0.0
  9     GRAS 8   50. 100     0.0   2.50  6.65 11.56 15.37  0.0   0.0   0.0   0.0   0.0   0.0
 10     PEAS10   40. 100     0.0   1.71  5.76 10.83 13.78  0.0   0.0   0.0   0.0   0.0   0.0
 11     FLAX11   50. 100     0.0   1.46  5.28 11.01  0.0   0.0   0.0   0.0   0.0   0.0   0.0
 12     $ENDFILE
End of file
```

Figure 4-4 Sample crop consumptive use file.

4.1.2.3 Jensen-Haise Potential Evapotranspiration Calculation

The Jensen-Haise ETP calculation is an empirically developed approach to crop consumptive use determination. The daily potential evapotranspiration is defined as

$$ETP = Ct(T-Tx)Rs \qquad (4.3)$$

where ETP is a depth, T is the daily average temperature, Rs is the daily solar radiation in inches of water equivalent and Ct and Tx are local climatic constants. Ct is defined as either

$$Ct = 1/((68-3.6\ E/1000.) + 13\ Ch) \qquad (4.4)$$

or

$$Ct = 1/((38-3.6\ E/1000.) + 7.3\ Ch) \qquad (4.5)$$

E is the elevation above sea level. Equation 4.4 deals with imperial units; eq. 4.5 being the metric equivalent. Tx is determined from either

$$Tx = 27.5-0.25\ (e_2-e_1) - E/1000. \qquad (4.6)$$

or

$$Tx = 27.5-0.33\ (e_2-e_1) - E/1000. \qquad (4.7)$$

Eq. 4.6 is for imperial units, 4.7 for metric calculations.

The Ch variable in equations 4.4 and 4.5 is a humidity index defined as

$$Ch = 37.5\ /\ (e_2-e_1) \qquad (4.8)$$

for e in mm Hg. For e in mbars, Ch is calculated with

$$Ch = 50\ /\ (e_2-e_1) \qquad 4.9$$

e_2 and e_1 in equations 4.6 through 4.9 are the saturation vapor pressures for the mean maximum and mean minimum temperatures, respectively, for the warmest month of the year.

For this study, Ct and Tx were determined for imperial units since the TIMS simulation model operates in that system. Mean minimum and maximum temperatures for Lethbridge in July are 80 and 53° F. For these temperatures, e_2 is 35.0 mbars, e_1 is 13.71 mbars, and

$$Ch = 50/(35.0-13.71) = 2.3 \qquad 4.10$$

therefore Ct = 0.011 and Tx = 19.1.

Equation 4.3 becomes

$$ETP = 0.011(T-19.1)Rs \qquad (4.3)$$

T and Rs are input through the climate file. Daily crop water use is then determined with equation 4.2.

4.1.2.4 Lateral Field File

LATFLD identifies the fields/crops served by each turnout on a distribution lateral. Also contained is the field information such as allowable depletion, rooting depth, storage capability, crop planting dates and water application efficiencies. All of the fields involved in this study are irrigated with wheel move sprinkler systems. Application efficiencies were generally set at 75 percent ('approximate value for a well designed sprinkler system, Hansen et al., 1980). In one case (turnout SLI1, Figure 3.4), the application efficiency was set at 70 percent because the farm delivery ditch is quite lengthy, and was reported to have significant seepage problems.

4.2 TIMS SCHEDULES

In order to perform the water balance in Chapter 5, simulation of crop water requirements was necessary. The TIMS soil moisture simulation and budgeting routines were utilized to determine plant moisture use for the test period. A sample output schedule that contains the

```
 1    PKLEDEK1      11        3.0        2.50
 2       1  94.0  2   513   75   4.2  8.3  630  2.50 199.0     0    0
 3       3  60.0  1   501   75   4.2  8.3  703  2.50 113.0     0    0
 4      99
 5    PKLEDEK2      12        3.0        2.50
 6       2  90.0  2   513   75   4.3  8.5  701  2.50 174.0     0    0
 7       4  50.0  2   515   75   4.3  8.6  703  2.50  97.0     0    0
 8      99
 9    PKLESLI1      13        3.0        2.50
10       1  50.0  2   508   75   4.3  8.6  629  2.50 194.0     0    0
11       2  50.0  1   501   75   4.3  8.6  703  2.50  97.0     0    0
12       3  50.0  2   511   75   4.3  8.6  629  2.50 194.0     0    0
13      99
14    PKLEWAT1      16        3.0        2.50
15       1  45.0  2   529   75   4.5  9.0    0  0.0    0.0     0    0
16       2  23.0  1   501   75   4.5  9.0  704  2.50  47.0     0    0
17       3  23.0  2   529   75   4.5  9.0    0  0.0    0.0     0    0
18       4  30.0  1   501   75   4.5  9.0  626  2.50 100.0     0    0
19       5  30.0  2   530   75   4.5  9.0    0  0.0    0.0     0    0
20      99
21    PKLEHEI2      15        3.0        2.50
22       1 140.0  2   508   75   4.4  8.9  629  2.50 277.0     0    0
23      99
24    PKLEHEI3      15        3.0        2.50
25       1  75.0  2   515   75   4.6  9.2  705  2.50 155.0     0    0
26      99
27    PKLEHER1      17        3.0        2.50
28       1  40.0  2   503   75   4.6  9.3  628  2.50  83.0     0    0
29       2  40.0  1   501   75   4.6  9.3  704  2.50  83.0     0    0
30     999
31    $ENDFILE
End of file
```

Figure 4-5 Sample lateral field file

LATERAL: PKLE TURNOUT: DEK1 FARM: 11 DATE: 711

FIELD NO.	CROP	ACRES	IRRIGATION REQ. AC-IN/AC	IRRIGATION REQ. AC-FT	LAST ORDER	NEXT IRRIGATION DATE	NEXT IRRIGATION CFS	NEXT IRRIGATION HRS
1	BARL	94.0	5.3	41.1	702	723	2.5	199.
3	ALFA	60.0	4.7	23.3	0	718	2.5	113.

	WATER ORDERS						FORECAST TURNOUT SCHEDULE											
TURNOUT	710		711		712		713		714		715		716		717			
	CFS	HRS	CFS	HRS	CFS	HRS	CFS	HRS	CFS	HRS	CFS	HRS	CFS	HRS	CFS	HRS		
DEK1	2.5	7.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.		
FIELDS	1	0 0 0	0	0 0 0	0	0 0 0	0	0 0 0	0	0 0 0	0	0 0 0	0	0 0 0	0	0 0 0		

NOTES FOR IRRIGATORS WATER ORDERS

Figure 4-6 Turnout schedule for the turnout DEK1 on the PKLE lateral.

information required is reproduced in Figure 4-5. TURNOUT schedules were produced for each delivery point in the study area. Figure 4.5 is a schedule for July 11th for the delivery DEK1. Two fields are supplied by turnout DEK1; 94 acres of alfalfa and a 60 acre barley crop. Based on climate and crop water use input files, the program determines when the soil moisture levels will fall below a set allowable depletion. An irrigation of the proper amount to refill the soil profile is forecast for the date when the depletion figure is reached. Note that water applications have been scheduled for both fields under the NEXT IRRIGATION heading. These values were used as the simulated equivalents to measured daily farm consumption.

The TIMS model has far greater capabilities than those discussed above. Information on TIMS is available in the United States government publication #REC-ERC-80-3 - Water Systems Management Users Guide.

5. ANALYSIS

In order to maintain accuracy, the study area was broken into 2 sections. Area 1-2 includes the farms served by turnouts between Sites 1 and 2, and Area 3-4 those farms between sites 3 and 4.

5.1 Area 1-2

Table 5.1 contains the daily operations data for the period June 1st through July 13th, 1981. Table 5.2 is the simulated equivalent, and was arrived at in the following manner.

Simulations of the 1981 crop year with the TIMS model produced schedules indicating amount of irrigation required by each crop and the optimum date to apply these quantities. Using these simulated farm requirements (Column 5, Table 5.2), a Site 1 flow was predicted with

$$Q1 = 1.814\ (Q2+Farm.use)^{0.858} \qquad (5.1)$$

Equation 5.1 is a regression fit between Site 2 daily discharges plus the farm requirements, (Columns 3 and 5, Table 5.1) and recorded Site 1 flows. The excellent fit ($r^2 = .99$) of the data points to the curve of equation 4.1 is illustrated in Figure 5.1.

Daily discharges at Site 2 were always held constant at the levels observed. The reasoning for this is straightforward. The level of water loss from any canal is

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TITLE OF THESIS **COMPUTER ASSISTED IRRIGATION WATER MANAGEMENT**

DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE IN WATER RESOURCES

YEAR THIS DEGREE GRANTED SPRING, 1983

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(SIGNED) .....

PERMANENT ADDRESS:

.....

.....

.....

DATED 19

DATE	SITE 1	SITE 2	LOSSES	FARM USE	DATE
601	24460.	21030.	3430.	0.	601
602	25541.	21967.	3574.	0.	602
603	27640.	23787.	3853.	0.	603
604	30936.	26648.	4288.	0.	604
605	35356.	29557.	3702.	2097.	605
606	37176.	30698.	1394.	5084.	606
607	38770.	32508.	1178.	5084.	607
608	44765.	38384.	1297.	5084.	608
609	47806.	40708.	2014.	5084.	609
610	53381.	44305.	3992.	5084.	610
611	60385.	49983.	5318.	5084.	611
612	69934.	61201.	3649.	5084.	612
613	38744.	33967.	-307.	5084.	613
614	20016.	16070.	-1138.	5084.	614
615	19733.	15524.	2112.	2097.	615
616	19233.	15007.	4226.	0.	616
617	17806.	13856.	3950.	0.	617
618	17789.	11985.	5804.	0.	618
619	16895.	14398.	2497.	0.	619
620	15925.	13479.	2446.	0.	620
621	15275.	12844.	2431.	0.	621
622	15156.	12844.	2312.	0.	622
623	18654.	15850.	2804.	0.	623
624	30196.	28596.	1600.	0.	624
625	46378.	43865.	2513.	0.	625
626	46693.	38117.	4496.	4080.	626
627	49688.	38952.	6656.	4080.	627
628	52969.	43099.	4815.	5055.	628
629	72459.	60326.	2197.	9936.	629
630	91009.	78484.	2589.	9936.	630
701	98433.	83511.	4986.	9936.	701
702	109381.	88291.	11154.	9936.	702
703	111461.	96870.	4655.	9936.	703
704	115371.	100400.	5035.	9936.	704
705	109873.	96300.	7717.	5856.	705
706	120132.	101156.	15118.	3859.	706
707	133909.	111210.	11759.	10940.	707
708	135335.	117057.	6730.	11548.	708
709	136462.	116337.	9865.	10260.	709
710	140315.	115179.	14876.	10260.	710
711	140969.	115206.	15503.	10260.	711
712	132797.	108709.	15229.	8859.	712
713	116430.	92073.	24357.	0.	713
714	40921.	39054.	1867.	0.	714
715	37605.	36040.	1565.	0.	715

Table 5-1 Daily record of weir flow volumes, losses and farm consumption in Area 1-2, June 1st - July 15th. Units are cubic meters per day.

DATE	SITE 1	SITE 2	LOSSES	FARM USE	DATE
601	24134.	21030.	3104.	0.	601
602	29230.	21967.	3523.	3740.	602
603	31201.	23787.	3674.	3740.	603
604	34287.	26648.	3899.	3740.	604
605	37412.	29557.	4115.	3740.	605
606	38634.	30698.	4196.	3740.	606
607	40569.	32508.	4321.	3740.	607
608	51750.	38384.	4966.	8400.	608
609	54200.	40708.	5092.	8400.	609
610	62951.	44305.	5501.	13145.	610
611	68873.	49983.	5745.	13145.	611
612	80504.	61201.	6158.	13145.	612
613	46421.	33967.	4674.	7780.	613
614	23898.	16070.	3083.	4745.	614
615	23300.	15524.	3031.	4745.	615
616	20121.	15007.	2741.	2373.	616
617	16209.	13856.	2353.	0.	617
618	14114.	11985.	2129.	0.	618
619	16813.	14398.	2415.	0.	619
620	15788.	13479.	2309.	0.	620
621	15078.	12844.	2234.	0.	621
622	15078.	12844.	2234.	0.	622
623	18427.	15850.	2577.	0.	623
624	32356.	28596.	3760.	0.	624
625	48665.	43865.	4800.	0.	625
626	42562.	38117.	4445.	0.	626
627	43451.	38952.	4499.	0.	627
628	47854.	43099.	4755.	0.	628
629	70805.	60326.	5819.	4660.	629
630	89569.	78484.	6425.	4660.	630
701	94728.	83511.	6557.	4660.	701
702	105100.	88291.	6783.	10026.	702
703	113832.	96870.	6936.	10026.	703
704	117416.	100400.	6990.	10026.	704
705	113253.	96300.	6927.	10026.	705
706	117616.	101156.	6993.	9467.	706
707	123646.	111210.	7070.	5366.	707
708	129556.	117057.	7133.	5366.	708
709	128829.	116337.	7126.	5366.	709
710	127660.	115179.	7115.	5366.	710
711	127687.	115206.	7115.	5366.	711
712	120209.	108709.	7028.	4472.	712
713	98723.	92073.	6650.	0.	713
714	43560.	39054.	4506.	0.	714
715	40347.	36040.	4307.	0.	715

Table 5-2 Simulated events for Area 1-2. Units are cubic meters per day.

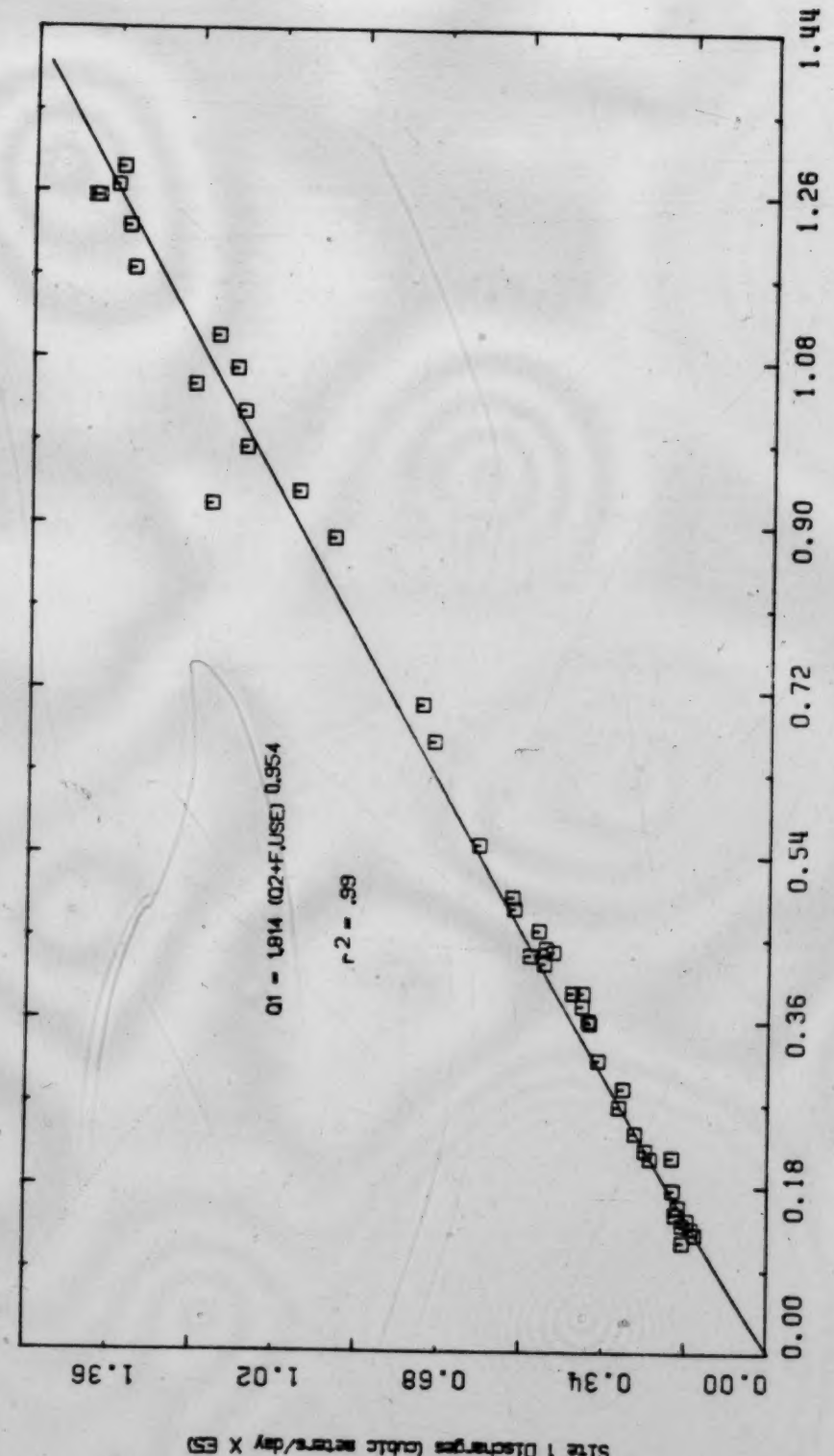


Figure 5-1 Regression curve for the data of sites 1 and 2.

related to the total flow volume. The losses recorded between weirs are a function of the water demand and the area through-flow. To compare simulated and actual daily flow losses, it was necessary to include the through-flow in the simulation to insure analytical consistency with actual conditions.

5.1.1 Discussion - Area 1-2

Relative water requirements for Area 1-2 from June 1st to July 13th are 431298 cubic metres of actual use, compared to 402171 cubic metres of simulated requirement. Thus, the net conservation equals

$$[(431298 - 402171) / 431298] 100 = 6.7 \text{ percent}$$

Such a quantity could mean a great deal in a heavy demand year. For instance, in 1977 the Lethbridge Northern district diverted 20862 hectare metres (169000 acre.ft) to service 45241 ha (111736 acres) of land. During August of that year, supply problems resulted in the LNID being forced to shut down for a number of days. Given that most of the water is consumed in June, July and August, then one could estimate that somewhere between 1000 and 1400 ha. m. of water (based on the total diversion) would have been conserved if the management program had been in place. Such quantities would definitely lessen the duration, and therefore the impact, of a supply related shutdown. Given that the quantities above

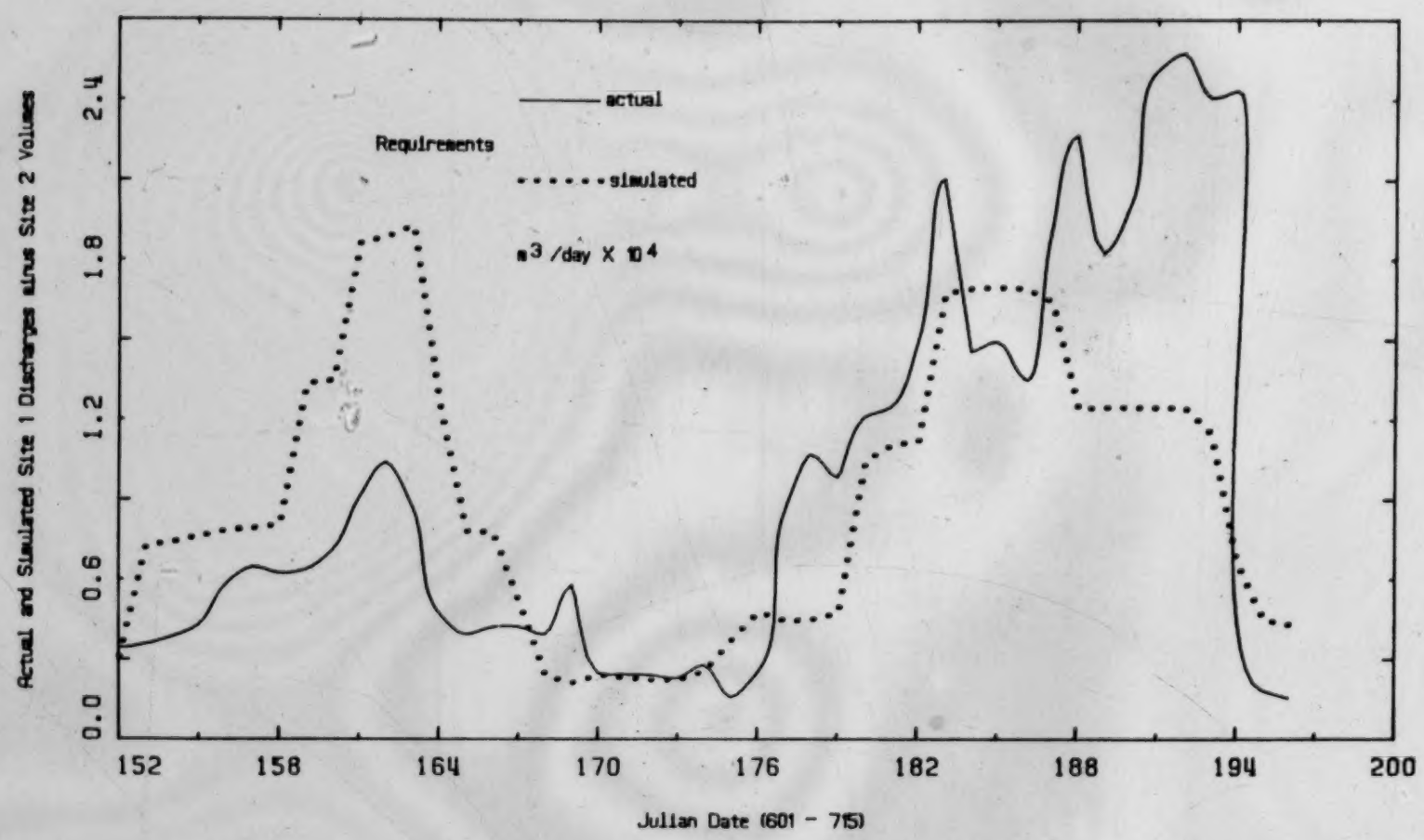


Figure 5-2 Simulated and actual water demands for Area 1-2.

represent approximately 6.8 days of full supply flow in the LNID main canal (full supply flow is about 17 metre^3/second or 600 cfs), it is possible that the 1977 shutdown could have been prevented altogether.

5.2 AREA 3.4

Tables 5.3 and 5.4 contain the actual and simulated operations, respectively, for Area 3.4. The approach utilized to generate Table 5.4 was the same as that described in Section 4.1. An equation

$$Q3 = 23.764(Q4+Farm.use)^{0.725} \qquad (5.2)$$

was fit to the data of Table 5.3. The week of June 16th-23rd was excluded due to a lack of confidence in the Site 4 flow data. It was felt that those discharges levels are much too low to be considered valid.

With an r^2 value of 0.90, Equation 5.2 was felt to be a reasonably accurate prediction tool. But while reviewing the plot of the data points against the curve (Figure 5.3), it was decided to eliminate 4 points that were well off the general data trend. Figure 5.4 is a plot of the final data set and the best fit equation

$$Q3 = 18.139(Q4+Farm.use)^{0.751} \qquad 5.3$$

This equation was utilized to simulate Site 3 daily

DATE	SITE 3	SITE 4	LOSSES	FARM USE	DATE
601	11785.	6877.	4908.	0.	601
602	11898.	6875.	5023.	0.	602
603	8553.	4775.	3778.	0.	603
604	3536.	1117.	2419.	0.	604
605	5063.	2178.	2885.	0.	605
606	7895.	3706.	4189.	0.	606
607	10087.	5130.	4957.	0.	607
608	12211.	6309.	5902.	0.	608
609	14258.	7592.	6666.	0.	609
610	14465.	5741.	8724.	2761.	610
611	15842.	6282.	9560.	3820.	611
612	22003.	11148.	10855.	0.	612
613	14525.	10861.	3664.	0.	613
614	7874.	3678.	4196.	0.	614
615	7730.	3099.	4631.	0.	615
616	4921.	1600.	3321.	0.	616
617	3132.	516.	2616.	0.	617
618	1969.	182.	1787.	0.	618
619	1643.	90.	1553.	0.	619
620	1394.	15.	1379.	0.	620
621	1253.	4.	1249.	0.	621
622	1385.	4.	1381.	0.	622
623	2249.	227.	2022.	0.	623
624	6345.	2244.	4101.	0.	624
625	17129.	7901.	9228.	0.	625
626	12644.	4090.	8554.	0.	626
627	11195.	3141.	8054.	0.	627
628	13721.	4883.	8838.	0.	628
629	20275.	11390.	8885.	0.	629
630	23575.	15798.	7777.	0.	630
701	23624.	15869.	7755.	0.	701
702	22824.	20709.	2115.	0.	702
703	36837.	21667.	15170.	0.	703
704	37874.	21108.	12946.	3820.	704
705	33482.	17868.	11794.	3820.	705
706	36124.	18634.	7981.	9509.	706
707	43778.	20702.	12903.	10173.	707
708	48512.	22660.	15679.	10173.	708
709	48157.	23245.	14739.	10173.	709
710	48842.	22532.	16137.	10173.	710
711	48484.	21758.	16553.	10173.	711
712	44965.	17739.	18439.	8787.	712
713	41366.	17905.	23461.	0.	713
714	23669.	5762.	17907.	0.	714
715	22631.	4513.	18118.	0.	715

Table 5-3 Daily operations in Area 3-4 for the period 601 - 715. All values are cubic meters per day.

DATE	SITE 3	SITE 4	LOSSES	FARM USE	DATE
601	13820.	6877.	6943.	0.	601
602	13817.	6875.	6942.	0.	602
603	10508.	4775.	5733.	0.	603
604	3529.	1117.	2412.	0.	604
605	5828.	2178.	3650.	0.	605
606	8687.	3706.	4981.	0.	606
607	11089.	5130.	5959.	0.	607
608	12953.	6309.	6644.	0.	608
609	14885.	7592.	7293.	0.	609
610	17700.	5741.	8139.	3820.	610
611	18447.	6282.	8345.	3820.	611
612	24783.	11148.	9815.	3820.	612
613	19478.	10861.	8617.	0.	613
614	8637.	3678.	4959.	0.	614
615	7595.	3099.	4496.	0.	615
616	4623.	1600.	3023.	0.	616
617	1976.	516.	1460.	0.	617
618	903.	182.	721.	0.	618
619	532.	90.	442.	0.	619
620	139.	15.	124.	0.	620
621	51.	4.	47.	0.	621
622	51.	4.	47.	0.	622
623	1067.	227.	840.	0.	623
624	5960.	2244.	3716.	0.	624
625	15338.	7901.	7437.	0.	625
626	9354.	4090.	5264.	0.	626
627	7672.	3141.	4531.	0.	627
628	10686.	4883.	5803.	0.	628
629	25084.	11390.	9874.	3820.	629
630	30367.	15798.	10749.	3820.	630
701	30449.	15869.	10760.	3820.	701
702	35914.	20709.	11385.	3820.	702
703	36127.	21667.	11404.	3056.	703
704	32083.	21108.	10975.	0.	704
705	35575.	17868.	11354.	6353.	705
706	36416.	18634.	11429.	6353.	706
707	38657.	20702.	11602.	6353.	707
708	40740.	22660.	11727.	6353.	708
709	41355.	23245.	11757.	6353.	709
710	40605.	22532.	11720.	6353.	710
711	39785.	21758.	11674.	6353.	711
712	33664.	17739.	11160.	4765.	712
713	28353.	17905.	10448.	0.	713
714	12101.	5762.	6339.	0.	714
715	10072.	4513.	5559.	0.	715

Table 5-4 Simulated events for Area 3-4 for June 1st to July 15th. Units are cubic meters per day.

discharges (Column 2, Table 5.4) from Site 4 demand and simulated crop water requirements. Site 4 discharges were treated as a downstream requirement of Area 3-4; the same treatment was applied to Site 2 data for the Area 1-2 analysis.

5.2.1 Discussion - Area 3-4

From June 1st to July 15th, 1981, (excluding June 16th-23rd) the actual water consumption within Area 3-4 was 426292 cubic metres. Simulations for the same time period indicated a total required volume of 380627 cubic metres. The difference (45665 cubic metres) is 10.7 percent of the total volume actually used. Extrapolation of this value to the entire LNID would result in a net saving of 2232.2 ha. m (15.2 days supply - main canal) of water for the 1977 season - such a volume would most definitely have prevented the shutdown. At the 1974 diversion per hectare level for the Lethbridge Northern, (0.47 ha.m/ha) such a conservation plan would have allowed the irrigation of 4754 hectares (11741 acres) over and above the area actually irrigated.

Figure 5.5 is a representation of the actual and simulated relative water demands for Area 3-4. The period from June 16th to 23rd is noted by a dotted line breaking the simulated plot line. Data from that period was not considered, as previously discussed.

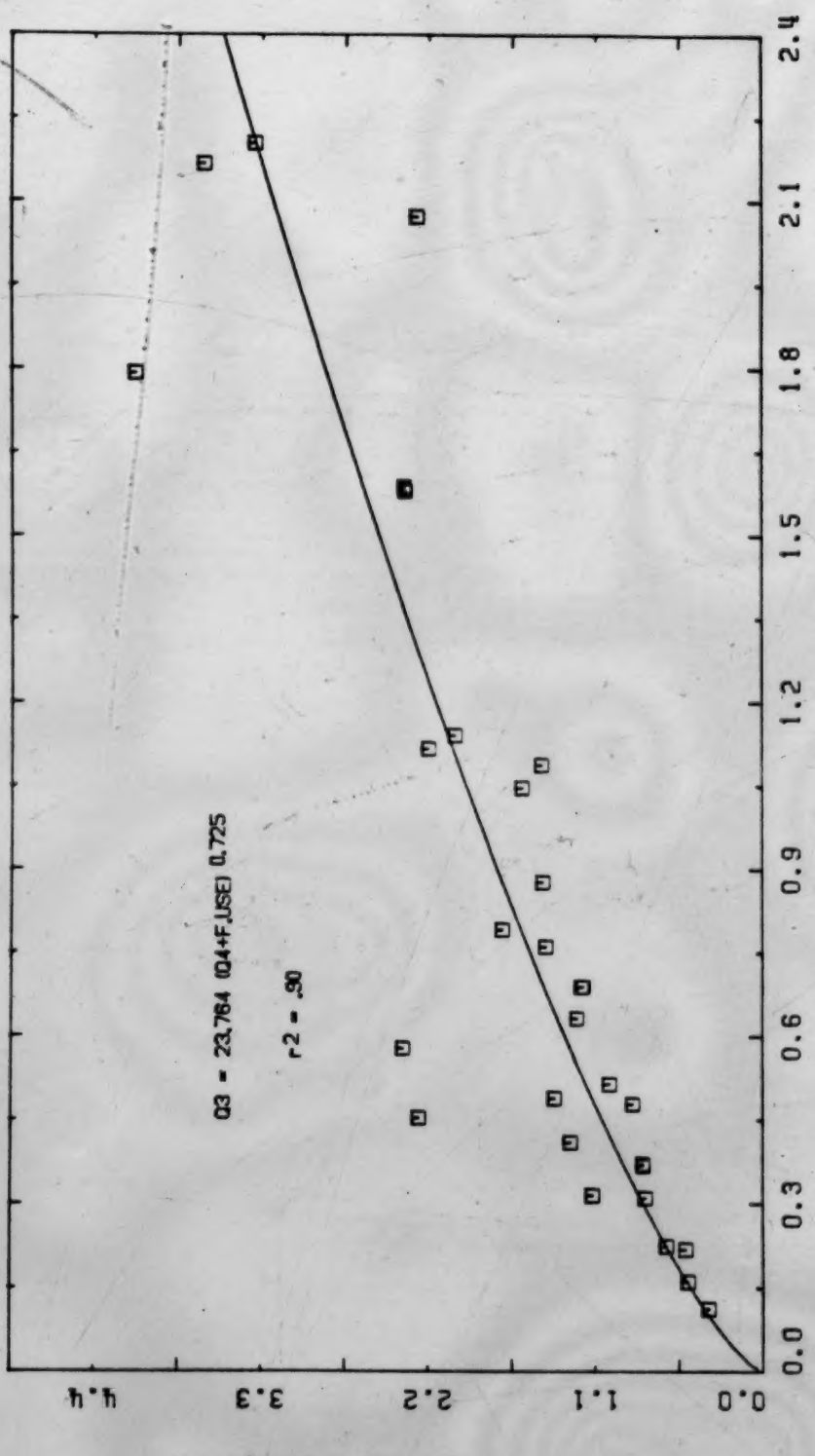


Figure 5-3 Initial regression fit for sites 3 and 4 data.

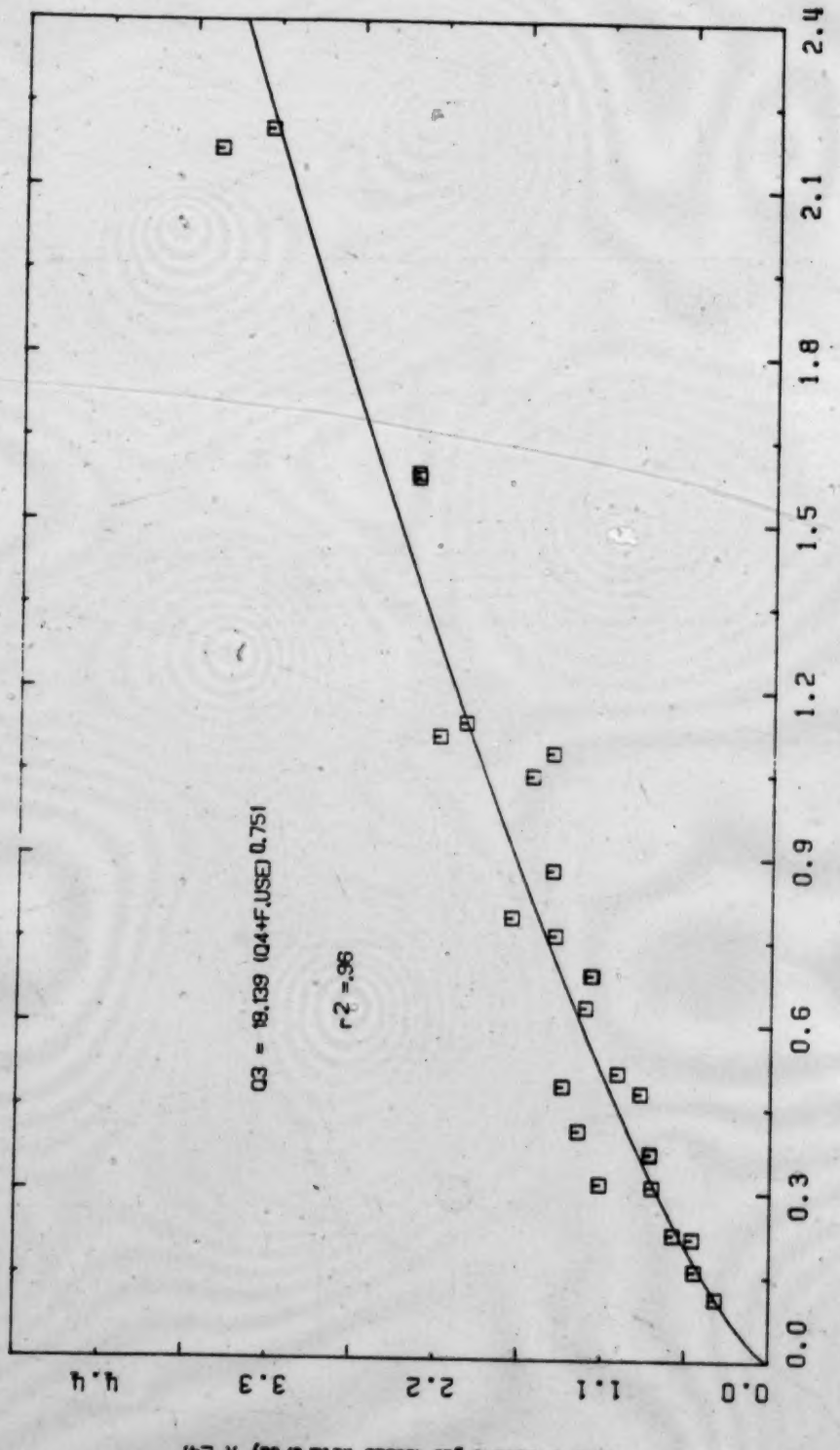


Figure 5-4 Final regression curve for sites 3 and 4 data

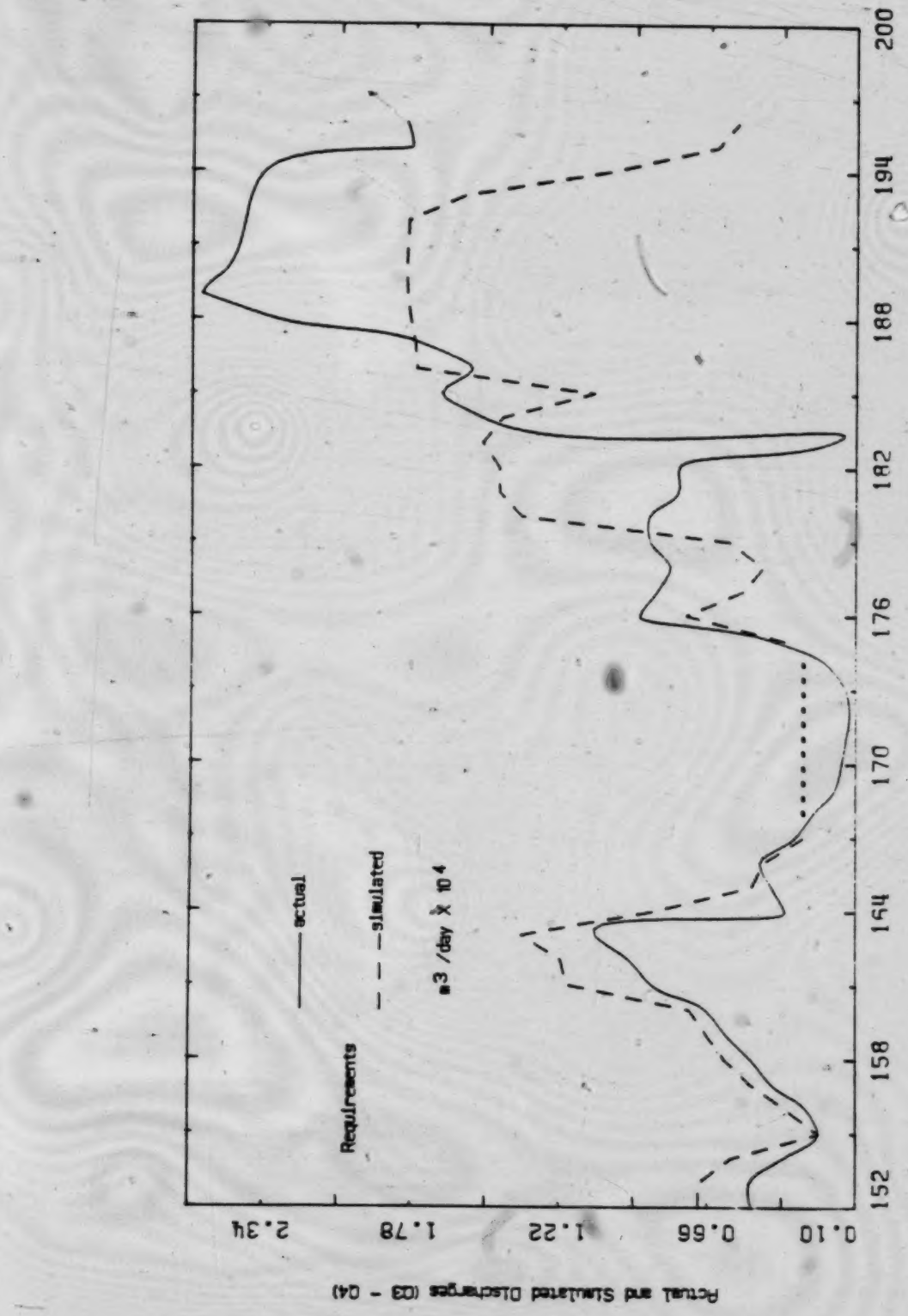


Figure 5-5 Simulated and actual water demands for Area 3-4.

5.3 Other Considerations

There are a number of considerations that weigh upon the discussion in Sections 5.1.1 and 5.2.1. The critical points are:

1. Peak demands
2. System throughflow / Return Flow

5.3.1 Peak Demands

Simulated and actual demand curves in Figures 5.2 and 5.5 are distinctly bi-modal. A dominant mode in the late June - early July period is characteristic of the recorded demand curves. Simulated values, on the other hand, do not display a dominant mode to the same degree. Obviously, attenuation of peak demand levels in this manner is advantageous in terms of lowering required system capacity. Further advantages are apparent. Early June is the peak discharge period for Southern Alberta rivers. Supply levels are therefore at the seasons highest point. Heavy withdrawals for irrigation will generally have little or no impact on the total stream discharge. This is in direct contrast to the July situation, when demand is rising, and river discharges are rapidly falling off.

5.3.2 Return Flow

The principle of the management process presented in this study does not recognize a need for significant quantities of return flow. Schuler (1976) indicated return

flow levels in 1972-73 to be in the range of 11 to 33 percent for the Lethbridge Northern and St. Mary's districts. Such volumes can be reduced dramatically with computer management if a reasonable storage capability is built into the conveyance system. Quantities released from a local reservoir would be pre-allocated to particular farms/fields; no unallocated volumes are released, therefore only minor spillwater volumes, associated with farm water management, would be returned to river flow.

Gross diversion and return flow totals for four southern Alberta districts for the period 1972-77 are presented in Table 5.5. The average spillwater volume for the 6-year period is 12867 ha.m (104238 acre ft.). For the unit consumption use values in Table 5.5, such a volume could theoretically irrigate 26282 to 50357 ha. (73000 to 133600 acres) of land, over and above the total area actually receiving water. While achieving such a high level of return flow elimination is not realistic, the figures do illustrate the potential benefits of reducing return flow volumes.

Attempting to quantify the return flow reduction that would be achieved by computer management is difficult. Column 4, Table 5.5, lists the return flow as a percent of the total diversion. The years of 1973, 1974, 1976 and 1977 were warm, dry years; consequently the ratio of return flow to total diversion reflects efforts to minimize spillwater losses. In spite of this, 14-16 percent of the total

YEAR	TOTAL DIVERSIONS (ha. m.)	RETURN FLOW (ha. m.)	% of TOTAL Diversion	CONSUMPTIVE USE (m)	RETURN FLOW / C.U. (ha)	ACTUAL AREA IRRIGATED (ha)	POSSIBLE INCREASE AREA IRRIGATED %
1972	60387	14732	24	.375	39285	121685	19.6
1973	89241	14593	16	.418	34911	178427	19.6
1974	78730	11284	14	.430	26282	156729	16.8
1975	42932	11985	28	.238	50357	130613	38.6
1976	79890	11882	15	.399	29779	169896	17.5
1977	89593	12727	14	.390	32633	196425	16.6

Table 5-5 Diversions, return flow and consumptive use for the LNID, MVID, SMRID and UID (source: Robinson, 1978)

diversion simply flowed through the system. Robinson (1978) reported the LNID spilled 9 percent of their total supply in 1977 - then shut down when the Keho Lake Reservoir ran out of water.

For illustrative purposes, assume that 30 to 80 percent of the spillwater could be saved with the simulation model (this range should cover the conservative and liberal estimates). With this range in mind, and including the conservation levels discussed in Sections 5.1.1 and 5.2.1, the possible conservation total with computerized irrigation manangement would lie somewhere between the limits 9.45 and 17.9 percent of the total diversion. These figures are calculated from the 1977 LNID return flow volume of 9 percent. That was the lowest level recorded by any district for the 3 year period 1975-1977. If the return flow volume is taken as 15 percent (average for the 4 dry years - '73, '74, '76, '77), the limits became 11.25 and 22.7 percent overall.

6. SIMULATION OF DAILY AND SEASONAL HEADGATE REQUIREMENTS

6.1 Introduction

The simulations of the previous chapter dealt with a year that was generally 'average' in terms of climatic occurrences. Water management in such a year is not as critical as for years of extreme climatic conditions. In this chapter, headgate demands for two such years are simulated with the TIMS model. The first year, 1977, is one of the heaviest irrigation water demand years on record. The second, 1978, is a year in which 21.3 inches of rainfall were recorded from April 1st to September 30th. As well, several simple management approaches are applied to the 1977 season, in an attempt to lower peak water requirements, thereby allowing for economizing on the delivery system capacity.

6.1.1 General Assumptions

The following assumptions are held consistent throughout this chapter.

(1). Crop mix - the Economics branch of Alberta Agriculture provided the following crop mix for the LNID in 1977.

Crop	% total acreage	acreage	comments
wheat	17.7	17578	
oats	4.8	4767	includes greenfeed
barley	35.2	34957	included silage
flax	0.7	695	
mixed grains	0.6	596	
peas	1.2	1192	
corn	1.2	1192	
sugar beets	5.8	5760	
alfalfa	22.8	22643	
summer fallow	3.7	3674	
total	100.0	99310	

(2). Initial soil moisture conditions were always set at field capacity. This approach was adopted to eliminate uncertainty about the boundary conditons.

(3). Climate data from the CDA Research Station at

Lethbridge was input as the climate data for the LNID.

(4). The district was broken into 2 areas: the KEHO area comprises all the land that draws on the Keho lake reservoir. The rest of the district, designated LNID south, is supplied from the stream flow of the Oldman River (Figure 6-1). An approximate acreage breakdown has Keho serving 57000 acres, and the main canal 42300. All of the simulations were performed for the LNID south region only. To obtain a daily demand at Keho lake, the discharge for that date for the south region is multiplied by 1.3475 (57000./42300.). Since there is no variation in parameters between the two areas (except for size), then it is correct to assume the Keho demand will reflect the LNID south region demands exactly.

(5). Maximum capacity of the LNID main canal is 600 cfs.

(6). Soil types were assumed to be 50 percent silt loam, 25 percent clay loam and 25 percent sandy loam. Soil moisture storage capability was assigned according to approximated values for the three soil types.

(7). The Hobb's ratio curves were utilized to determine crop moisture use. Plots of the these curves are included in Appendix A.

(8). Conveyance efficiency levels were taken as 70 percent; farm efficiency levels were set at 50 percent (Environment Council of Alberta, Oldman River Basin Report).

(9). All crops were assigned a rooting depth of 1.2 meters.

6.2 The 1977 Crop Year, LNID

The 1977 flow simulations were run with all crops at a 50 percent allowable depletion. Grain crops were planted from May 1st to 20th; sugar beets and vegetables were planted from May 20th to 30th. Perrenial crops such as alfalfa were treated as having been planted on the 1st of May.

6.2.1 1977 Daily Water Demand for the LNID South Region

The daily water demand for the LNID south region is presented in Figure 6-2. Two curves have been plotted: the daily requirement as predicted by the TIMS model, and a 5 day running mean of the same values. Discussion in section 2.4 indicated a confidence band of $\pm$ 2 days in evapotransporation simulation. It is reasonable therefore, to use the running mean curve as the daily district demand curve.

Diversion totals for the 1977 season, using the running mean curve, amount to 73315 acre-feet for the LNID south. If this is converted to a volume demand on Keho lake, ie

Keho Demand = 1.3475 X 73315

= 98793. acre-feet

then the total water requirement for the entire district in 1977 would be 172108. acre-feet. This value compares favorably with the actual diversion total of 169000. acre-feet in 1977 (ECA report). That value would have been somewhat higher if the district had had the capability to

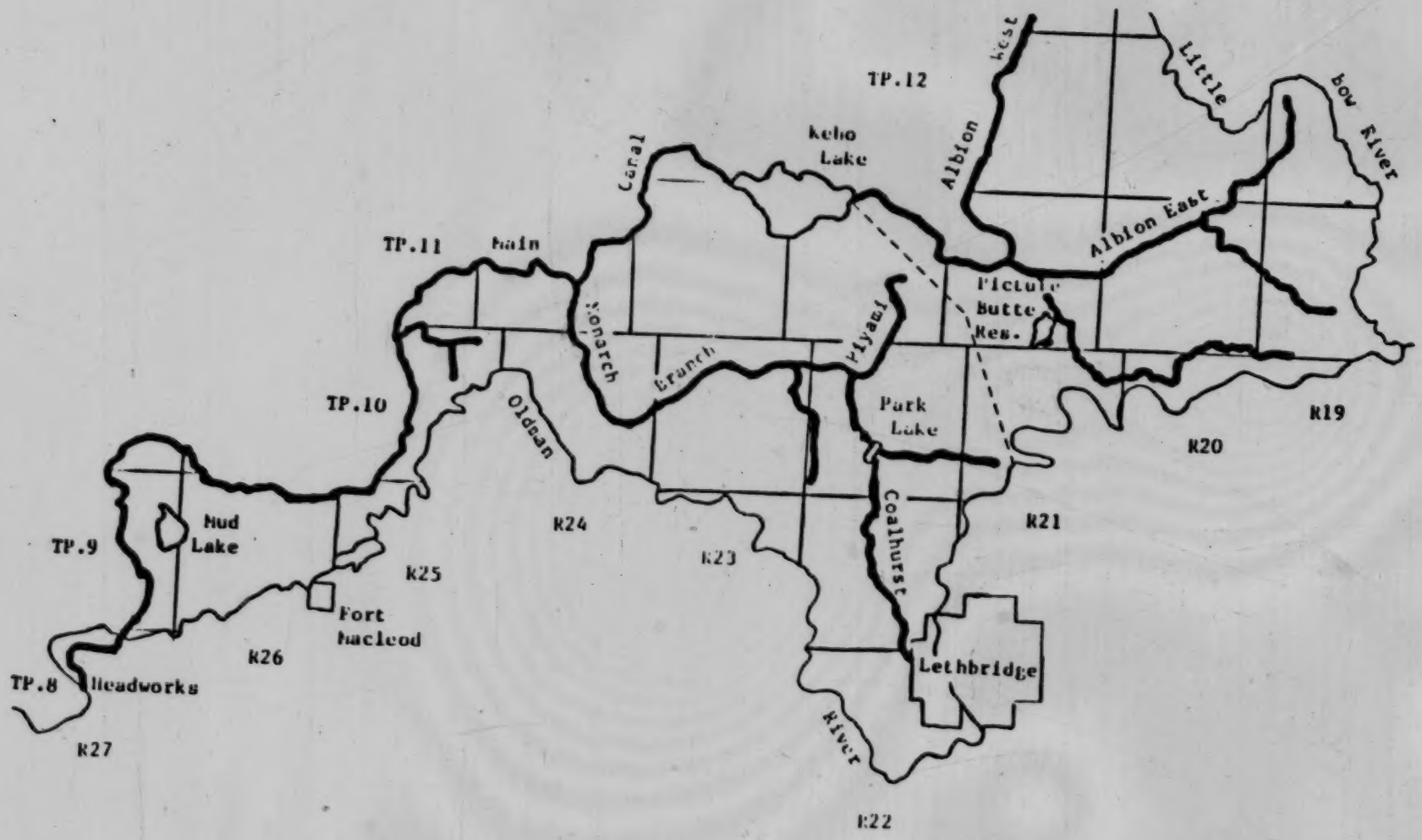


Figure 6-1 The LNID main distribution system, showing an approximate division line between the Keho lake area and the southern division.

meet the demand. This was not the case as 1977 was the year of the temporary shutdown.

The curves of Figure 6-2 demonstrate several points. Heywood, in determining mean annual irrigation requirements for southern Alberta, utilized a composite crop of 45 percent alfalfa, 45 percent grains and 10 percent sugar beets. He indicated that to raise the grain percentage would " reduce late and early season requirements but will increase peak demand." This statement is supported by the Figure 6-2 curves. Grouping the crop mix of this report after Heywood produces a composite crop of 59 percent grain, 29.1 percent alfalfa and 8.2 percent specialty crops. If the crop mix is to remain at these levels, the peak demands created will make optimal irrigation difficult in dry years, at least under current management practice. The LNID main canal cannot handle more than 60 percent of the peak flow requirements of Figure 6-2.

6.2.2 Simulated Peak Demand Levels

The simulated peak flow requirements in Figure 6-2 are some 400 cubic feet per second above the maximum capacity of the LNID main canal. Three points support the magnitude of the simulated discharges and explain why recorded peak demand has never reached such proportions:

(1). Optimal irrigation practice is not wide spread. Some discussions have indicated that most farmers only irrigate to 75 percent of optimal. This would reduce peak demand

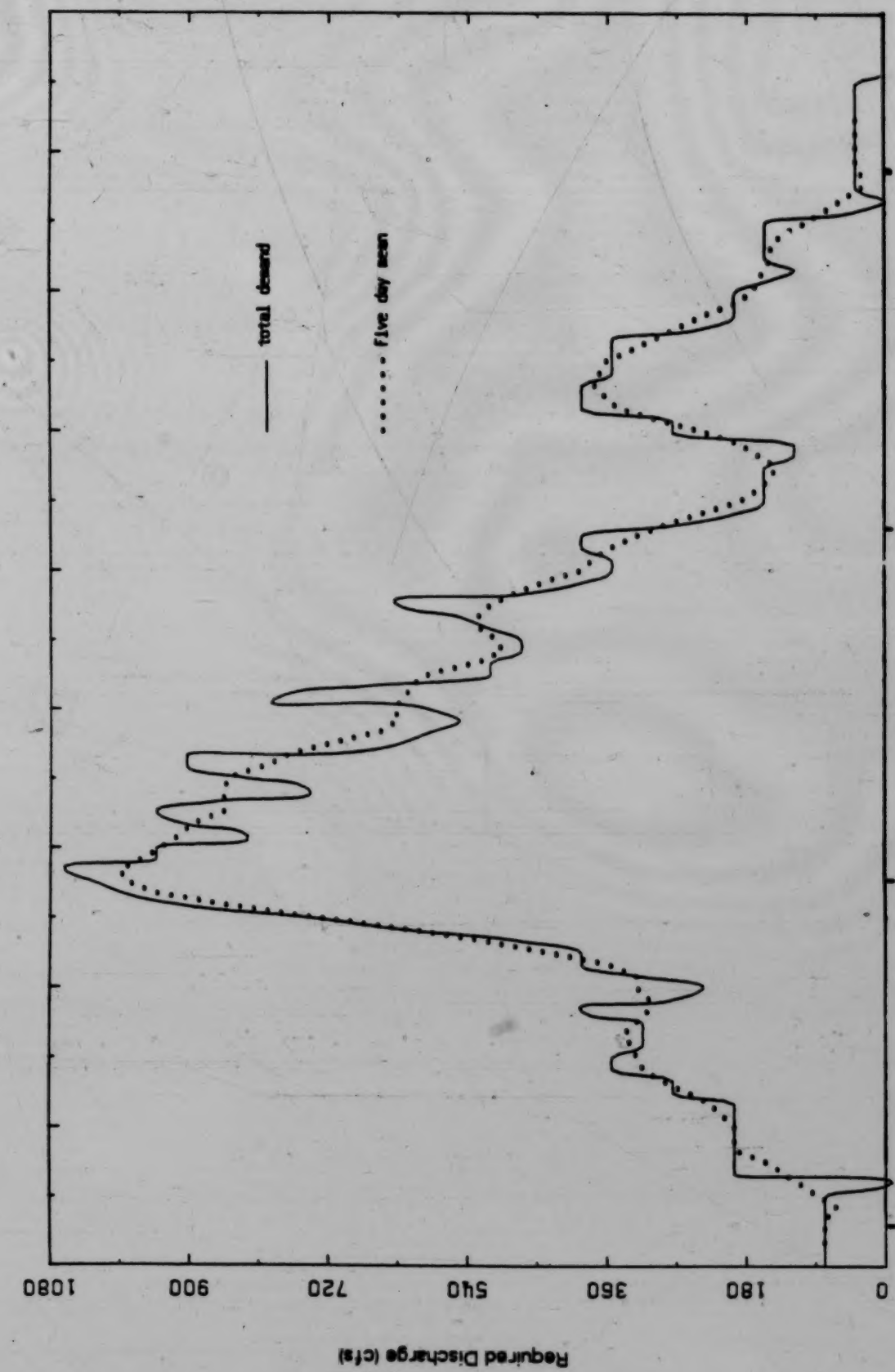


Figure 6-2 Total demand and five day running mean curves for the LNID south area, 1977.

levels accordingly. Heywood (1978) indicated that a drop of 20 percent in water utilized will drop the irrigation requirement by 32 percent.

(2). Some farm application systems may not have the capability to meet irrigation requirements in a dry year like 1977, consequently actual water use would be below a theoritical demand based on crop water requirements.

(3). In the simulation process, each farm delivery discharge was set at 2.75 cfs. This value is somewhat greater than the average farm demand - the sprinkler irrigation farmers involved in this study (all with half mile wheel move systems) had a average delivery volume of 1.8 cfs.

The factors discussed above have caused for the simulated peak demands to be somewhat higher than recorded values. Section 6.3 of this report deals with management approaches that can effectively lower peak requirements while maintaining optimal irrigation processes.

6.2.3 Monthly Consumptive Use Values by the Major Crops, 1977

The monthly consumptive values for the 1977 crop season, as determined with the TIMS model and the Hobbs coefficients are included in Table 6-1.

PLANTING DATE	CROP	MAY	JUNE	JULY	AUGUST	SEPT.
501	alfalfa	3.48	6.97	6.56	4.03	2.31
501	wheat	0.90	4.79	6.11	1.38	-
501	barley	1.01	4.84	5.54	0.40	-
501	oats	1.05	4.64	6.41	1.55	-
501	pasture	1.84	4.59	5.13	3.16	0.98
501	flax	1.02	4.02	5.96	2.03	-
501	peas	1.15	4.39	5.29	2.24	-
501	corn	0.79	2.34	4.32	3.72	1.51
518	s.beets	0.28	2.83	4.69	3.93	2.25

TABLE 6-1. MONTHLY CONSUMPTIVE USE IN INCHES BY THE MAJOR CROPS, 1977 SEASON

PLANTING DATE	CROP	MAY	JUNE	JULY	AUGUST	SEPT.
501	alfalfa	2.83	6.68	6.84	5.17	1.37
501	wheat	0.72	4.62	6.38	2.19	-
501	barley	0.78	4.67	5.75	0.49	-
501	oats	0.81	4.49	6.70	2.14	-
501	pasture	1.49	4.42	5.36	4.06	0.80
501	flax	0.78	3.89	6.25	2.73	-
501	peas	0.94	4.23	5.53	2.92	-
501	corn	0.60	2.27	4.55	4.76	1.16
518	s.beets	0.20	2.74	4.93	5.02	1.42

TABLE 6-2. MONTHLY CONSUMPTIVE USE IN INCHES BY THE MAJOR CROP GROUPS, 1978 SEASON

6.3 Lowering Peak Irrigation Demand with Management Practices

Discussions in section 6-2 indicated that the large percentage of grain crops in the LNID created high mid-season water demands. Certain management approaches can be utilized to attenuate these peaks. The two most obvious parameters to vary are the crop planting dates and safe allowable depletion levels. The TIMS model can be utilized to determine the most advantageous manipulation of these variables.

The water requirements of the 3 major crops (alfalfa, barley and wheat), as determined in section 2, are plotted in Figure 6-3 along with the total demand curve. Inspection of this figure indicates the peak requirements of all 3 crops intersect in late June - early July, creating the high total demand at that time. In order to lower the peak of the total demand curve, this intersection must be prevented with some type of management decision.

6.3.1 Shifting Peak Crop Water Demands

Simplicity was taken to be the key in selecting a management strategy that would reduce peak demands. Since the grain crops create most of the peak demand, it follows that management procedures should be directed at them. Figure 6-4 illustrates the demand curves for wheat and barley. These curves both peak under the total demand peak: consequently, to lower the total demand peak, the wheat and

barley demand curves must be shifted, one to the left, the other to the right.

To attain a feel for which crop to shift which way, the Hobb's ratio curves for each were plotted in Figure 6-5. From these curves, several observations indicate that wheat crop demands can be shifted towards August with reasonable success. While the early portions of the curves are nearly identical, the wheat curve peaks slightly higher and later, and maintains a demand for a longer period. Based on these observations, the following criteria were set as management approach 1.

(1). All barley to be planted prior to May 15th.

(2). Planting dates for wheat are close to but not beyond May 26th. This criteria will allow 100 days prior to September 3rd for the wheat to mature. There is only a 2.5 percent chance of frost prior to that date.

(3). All 80 acre wheat parcels are set at 55 percent allowable depletion, except those on sandy loam soil. Moisture storage in sandy loam soil is not sufficient to allow 55 percent depletion.

6.3.2 Results - Approach 1

Figure 6-6 contains the initial wheat and total demand curves, and those curves that result from TIMS simulations with the approach 1 criteria in place. The wheat curve has shown some movement to the right; resulting in a lowering of the peak total demand by 119 cfs or 11.2 percent. The final

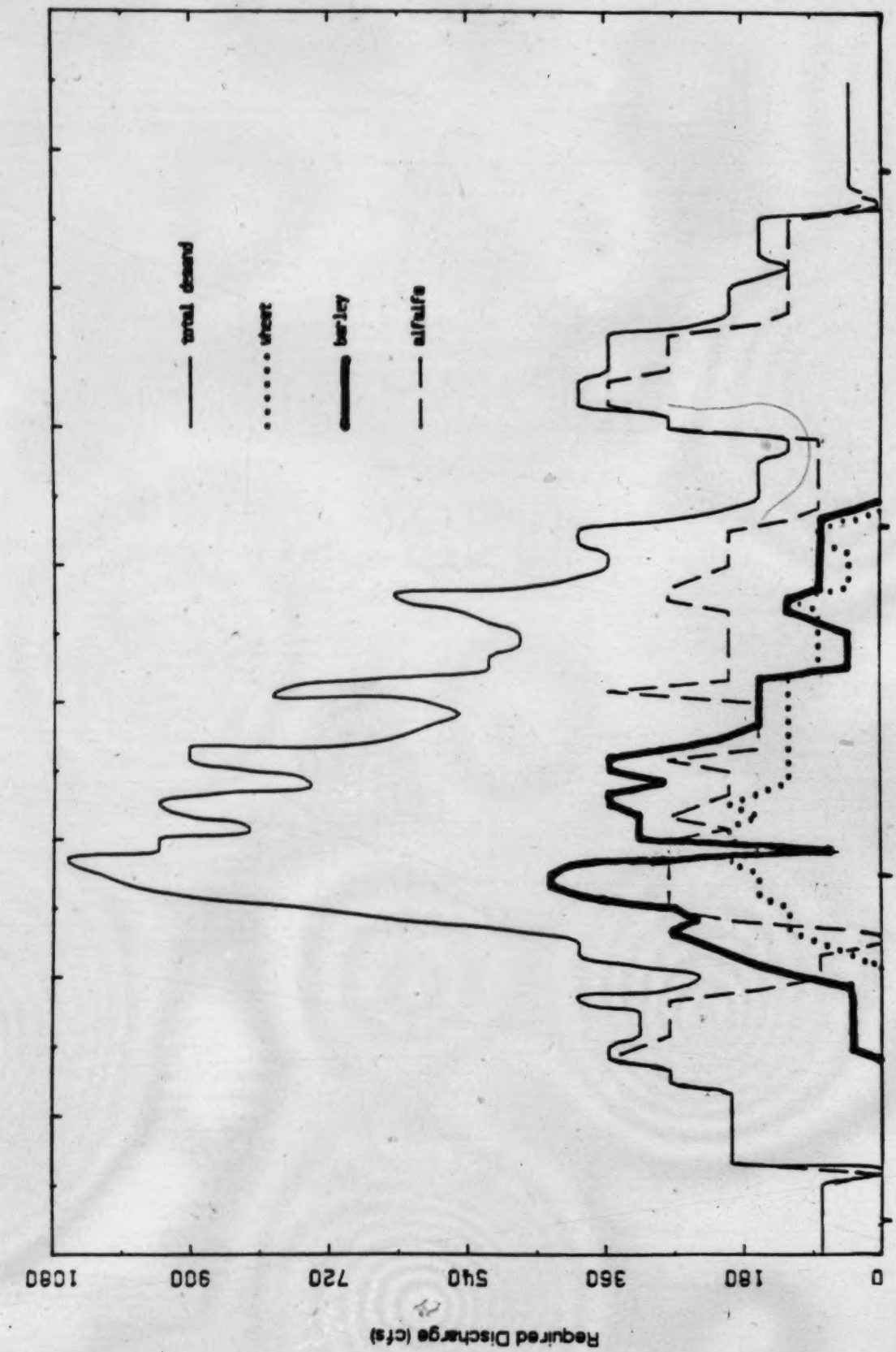


Figure 6-3 Demand curves for the major crops types in 1977.

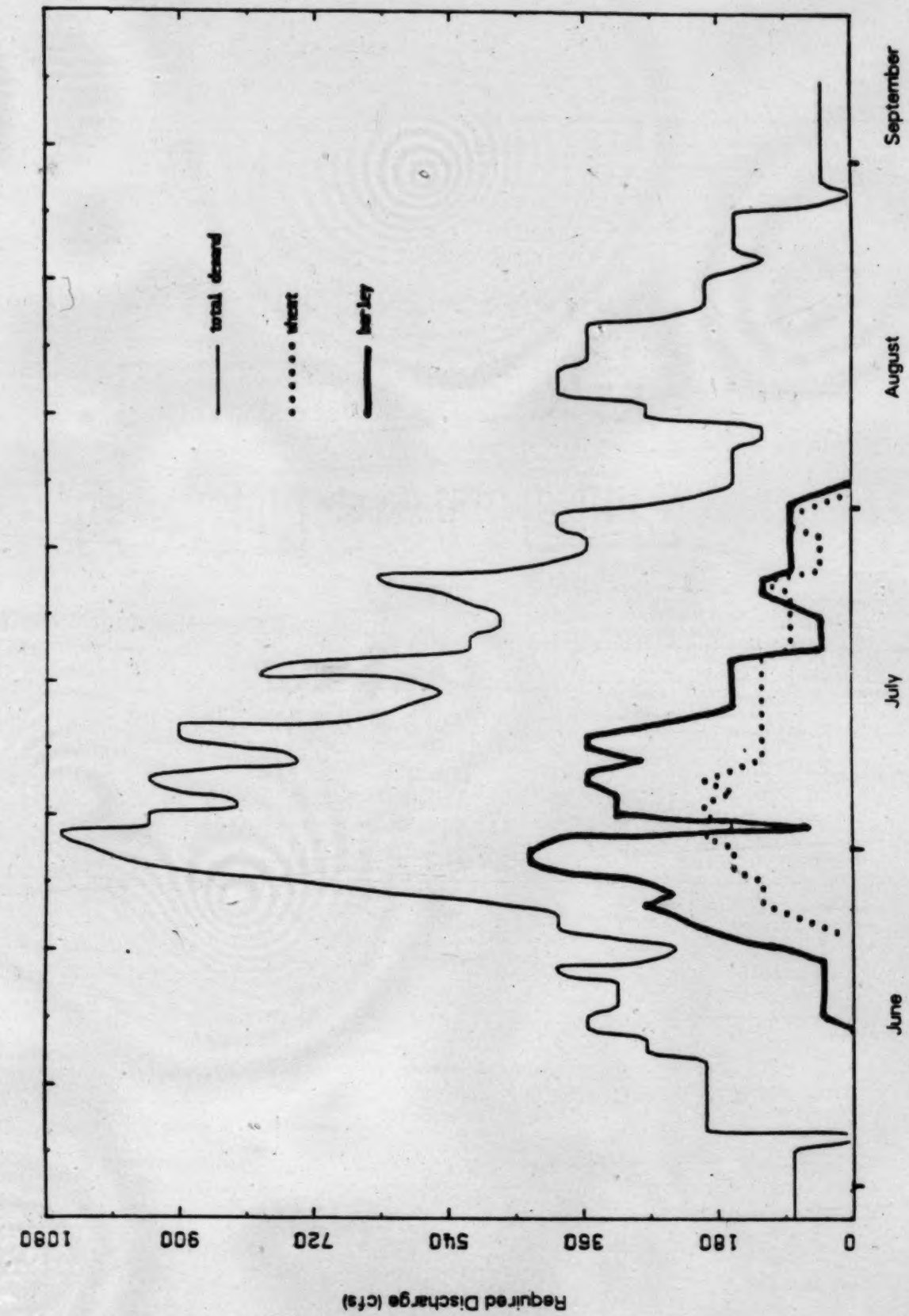


Figure 6-4 Major grain crop demand curves.

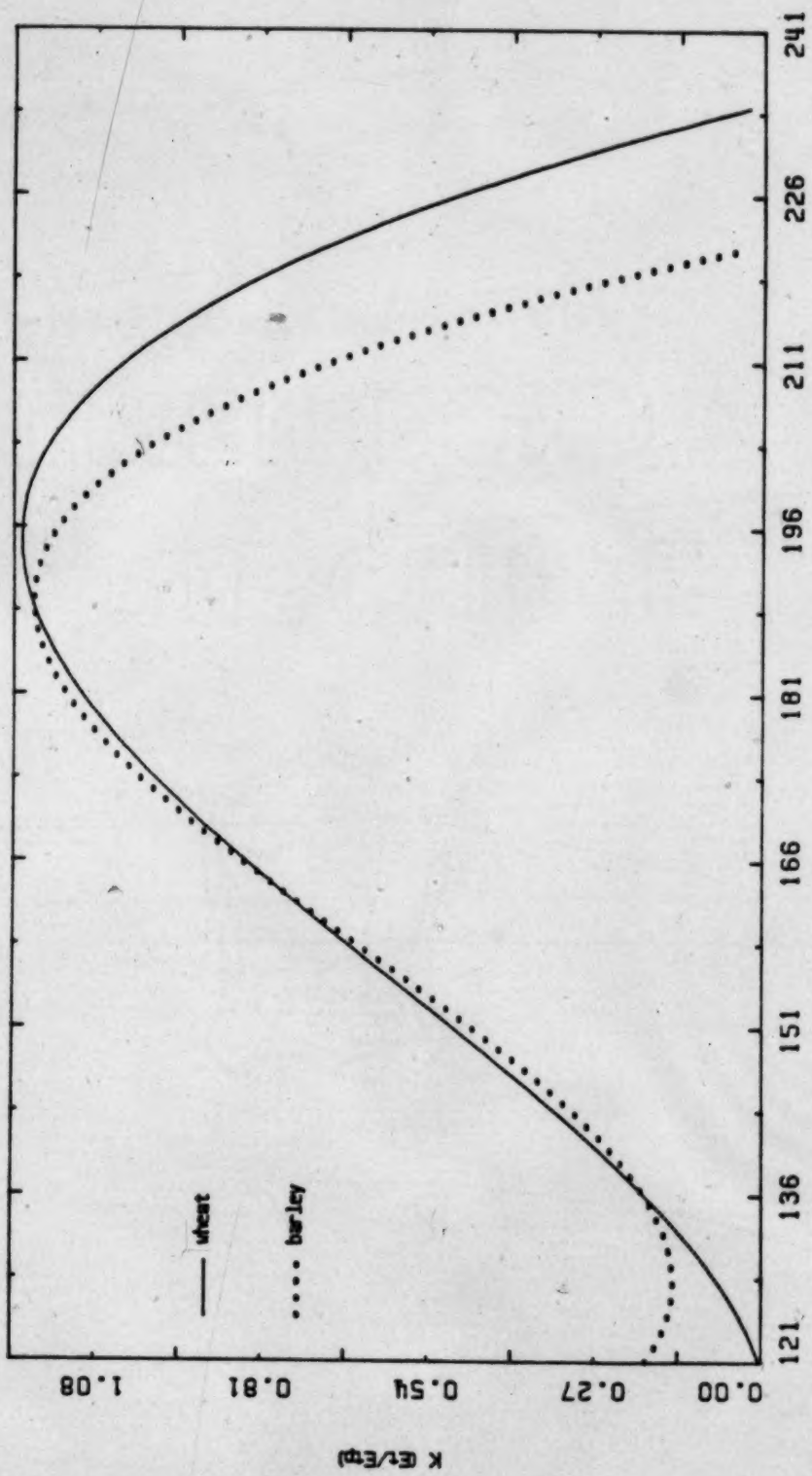


Figure 6-5 Hobbs ratio curves for wheat and barley.

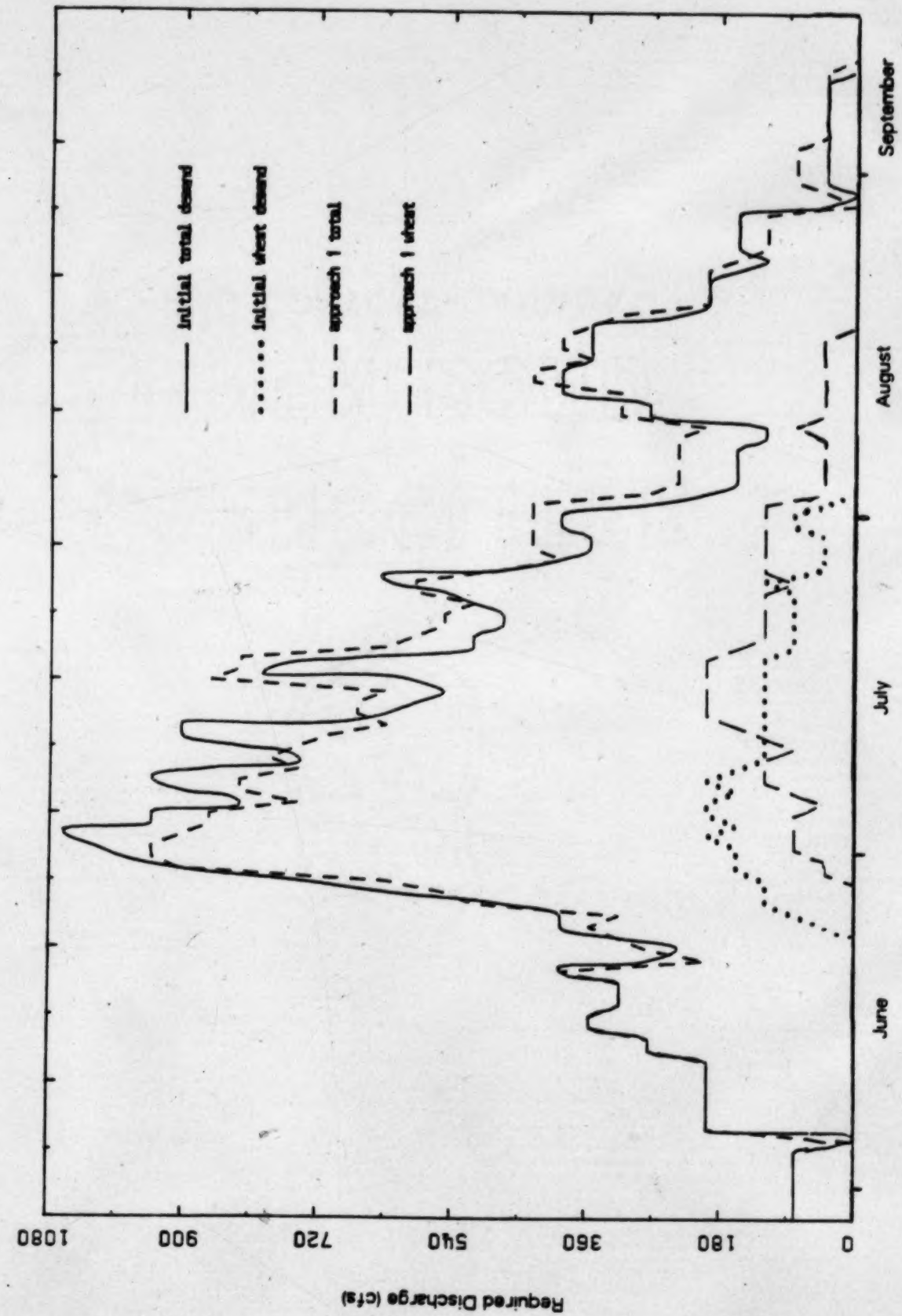


Figure 6-6 Comparison of the initial demand curves and those generated under approach 1 criteria

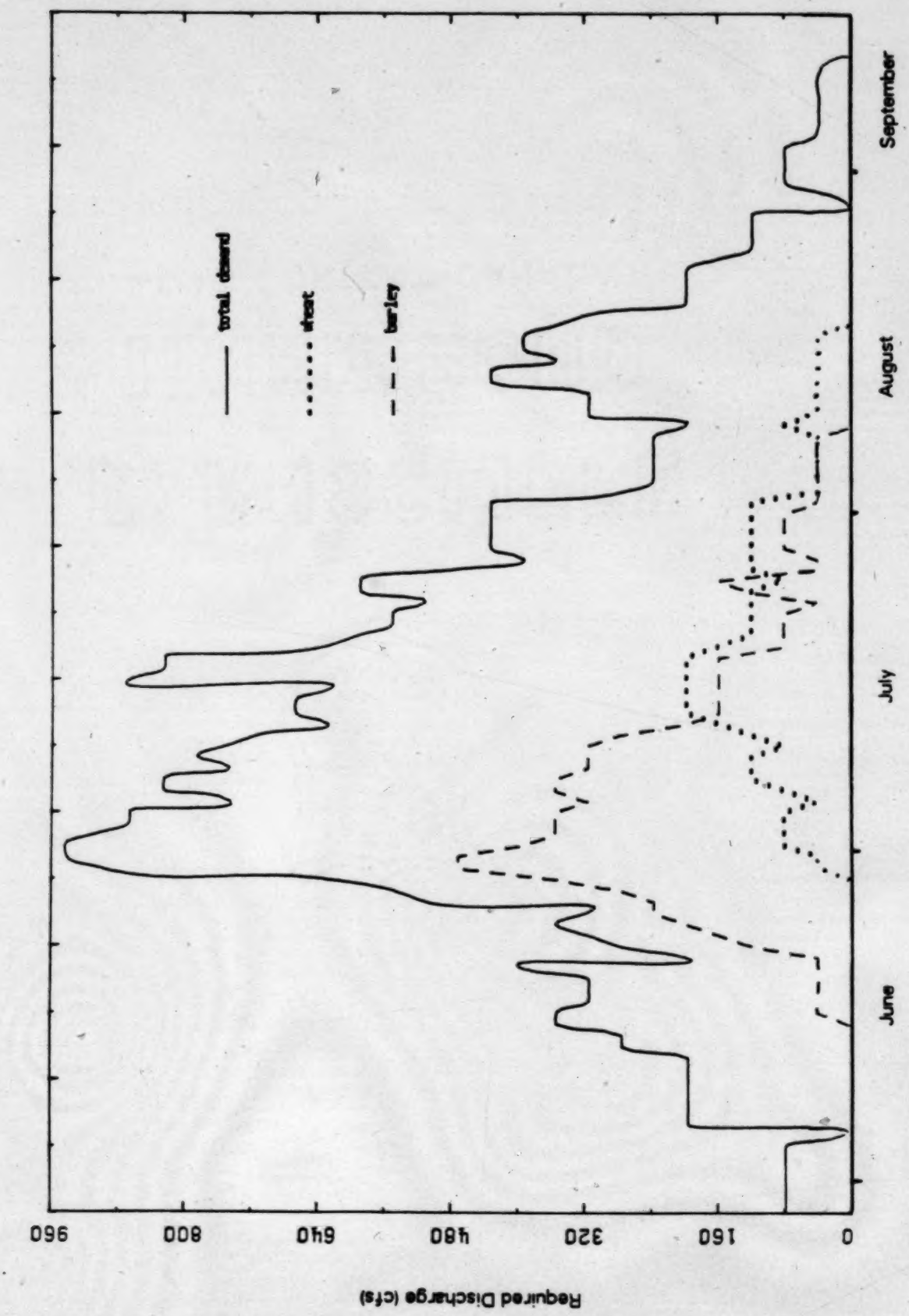


Figure 6-7 Grain crop demand curves for approach 1 criteria.

wheat, barley and total demand curves arrived at under the approach 1 criteria are plotted in Figure 6-7. Comparison to the curves of Figure 6-4 indicate the grain curves have shifted away from each other, thereby lowering peak water requirements.

6.3.3 Approach 2 Criteria

The success of approach 1 can be viewed in several ways. An 11.2 percent lowering of peak water requirements would realize a major economic advantage in terms of the required conveyance system capacity. However, other factors can be considered that indicate the curves of Figure 6-7 do not show the maximum separation of wheat and barley curves that is possible; hence the maximum attenuation of the peak flow requirements may not have been achieved. Under the first management approach, it was indicated that wheat requires water for a longer period than barley: this is evident in Figure 6-5. Under the following criteria, it is shown that this advantage is outweighed by 2 factors. First, barley matures about 10 days faster than wheat, therefore it can be planted 10 days later. Second, a major portion of the barley acreage each year is cut as silage after approximately 75 days. This portion of the barley crop can be planted fully 25 days later than wheat without fear of fall frost problems. With these factors in mind, and assuming approximate one half of the barley is silaged, the following criteria were developed.

(1). Planting date for approximately one half of the barley near to but not beyond June 6th. This allows 90 days to September 3rd.

(2). Silage barley planted near to but not beyond June 20th. This allows 75 days to September 3rd.

(3). All small barley parcels (80 acres or less) set at 55 percent allowable depletion, except those on sandy loam soil.

(4). All wheat crops are planted prior to May 10th.

6.3.4 Results - Approach 2

The wheat, barley and total demand curves generated with TIMS under approach 2 criteria are presented in Figure 6-8. Several factors are apparent: the grain curves have been separated quite well. The peak total demand has been lowered to 864 cfs, a drop of 18.6 percent from initial conditions, and 8.3 percent lower than the approach 1 peak requirement.

Figures 6-9 and 6-10 contain the actual and five day running average plots of initial total demand, and those of approach 1 and 2. Figure 6-10 demonstrates the trends of each condition very well. The curve of approach 2 clearly shows the greatest attenuation of the water demand. However, one disadvantage is encountered with this curve. The peak flow demand has been shifted about 20 days later in the season, to approximately July 20th. An irrigation district drawing much of its supply from natural streamflow could

find river supplies rapidly dwindling at that time of year.

6.4 1978 Crop Year, LNID

The simulations of section 6-2 of this report were carried out for one of the highest irrigation water demand years on record. Logically, it follows that simulations of a 'wet' year are valuable for comparitive purposes. The 1978 season was one of the wettest crop years in recent times (in terms of total precipitation during the crop year), with approximately 21.3 inches of rainfall between April 1st and September 30th. Consequently, 1978 was chosen as the wet year for TIMS modeling. However, simulations indicated several factors somewhat anomalous to expected conditions.

Several assumptions should be mentioned prior to discussion of the output. The 1978 crop mix differed so little from that of 1977 that the mix of the earlier year was utilized. This was not only advantageous in terms of study expediency, but also facilitates comparison to the 1977 demand curves. Planting dates and allowable depletion levels were held exactly as they were set in section 6-2.

6.4.1 1978 Daily Water Demand for the LNID South Region

Daily flow requirements for 1978 as determined by TIMS are plotted in Figure 6-11. Both the actual daily requirement and the 5 day running mean curves are shown. Close scrutiny indicates that simulated levels appear very high considering the rainfall received. Peak flow

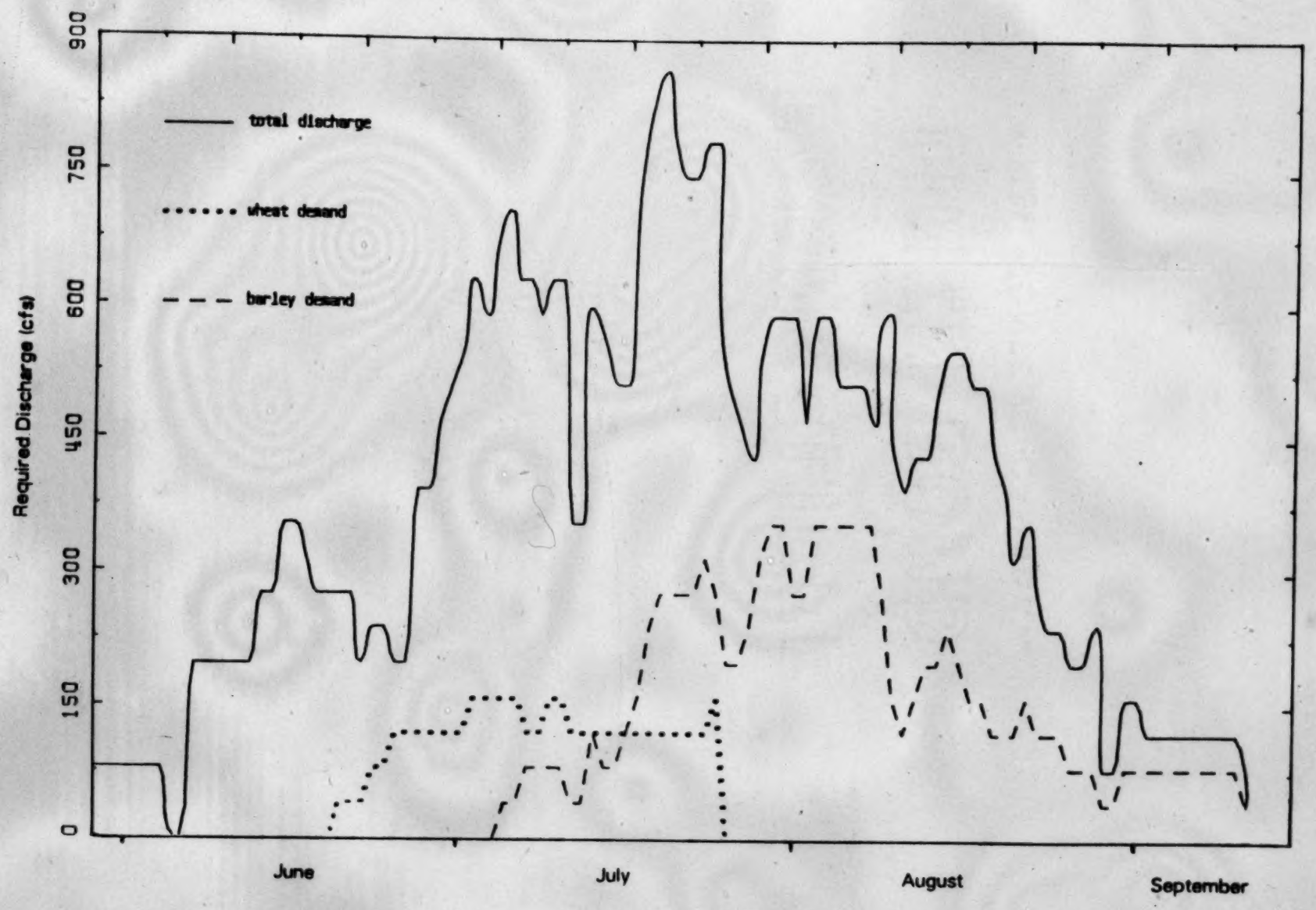


Figure 6-8 Grain crop demand curves for the approach 2 criteria

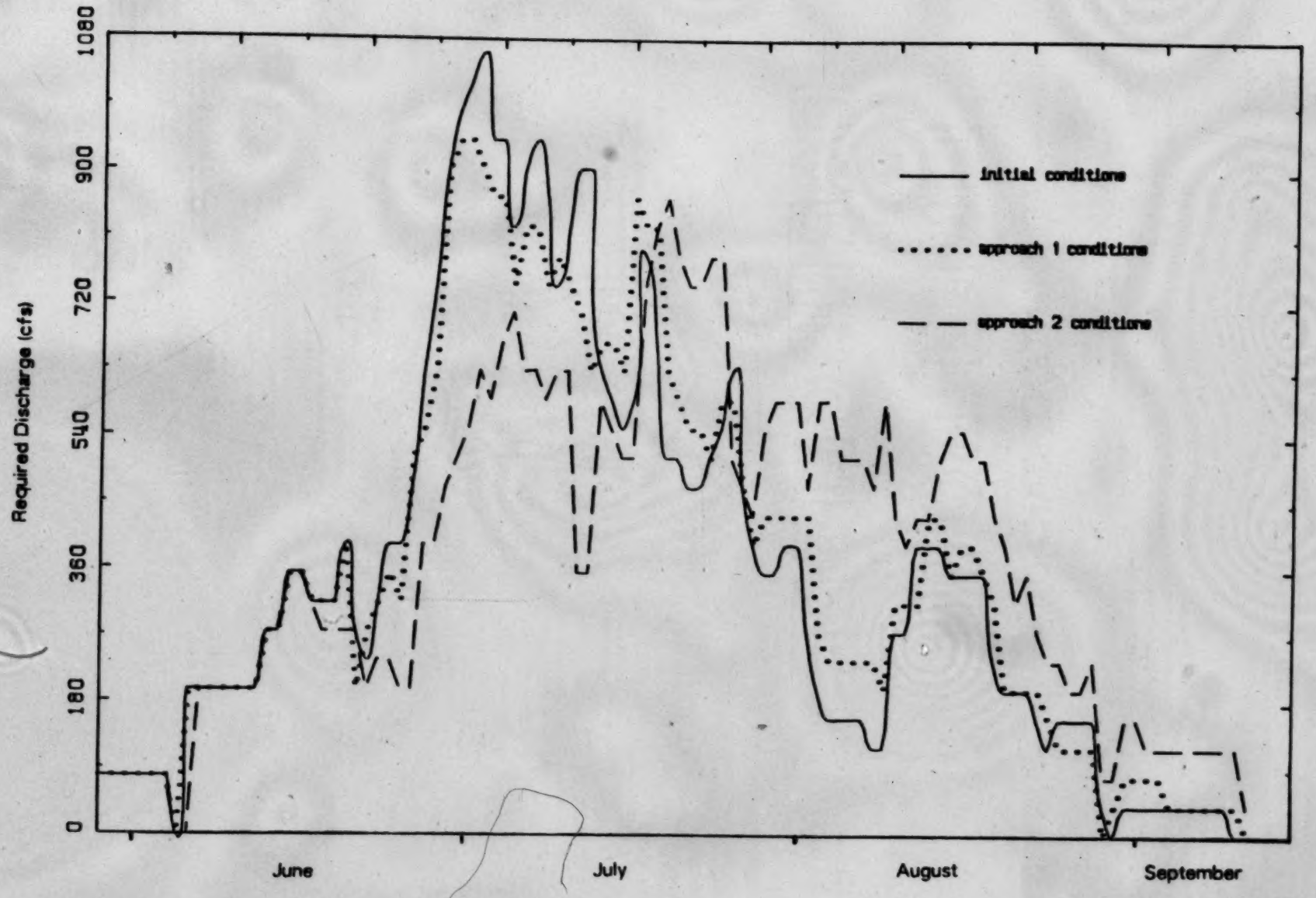


Figure 6-9 Total demand curves for approaches 1 and 2, and initial conditions.

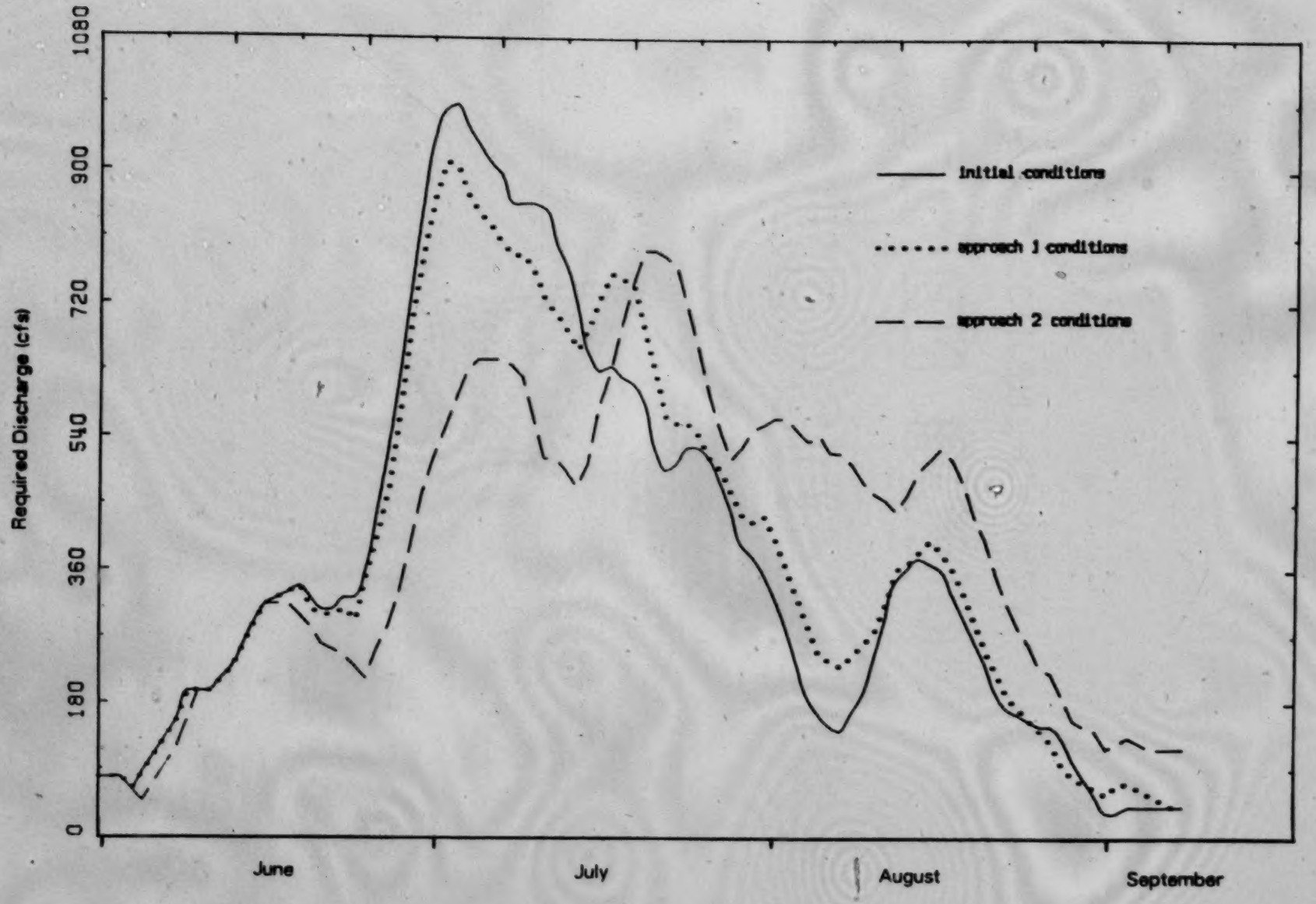


Figure 6-10 Five day running means for the curves of Figure 6-9.

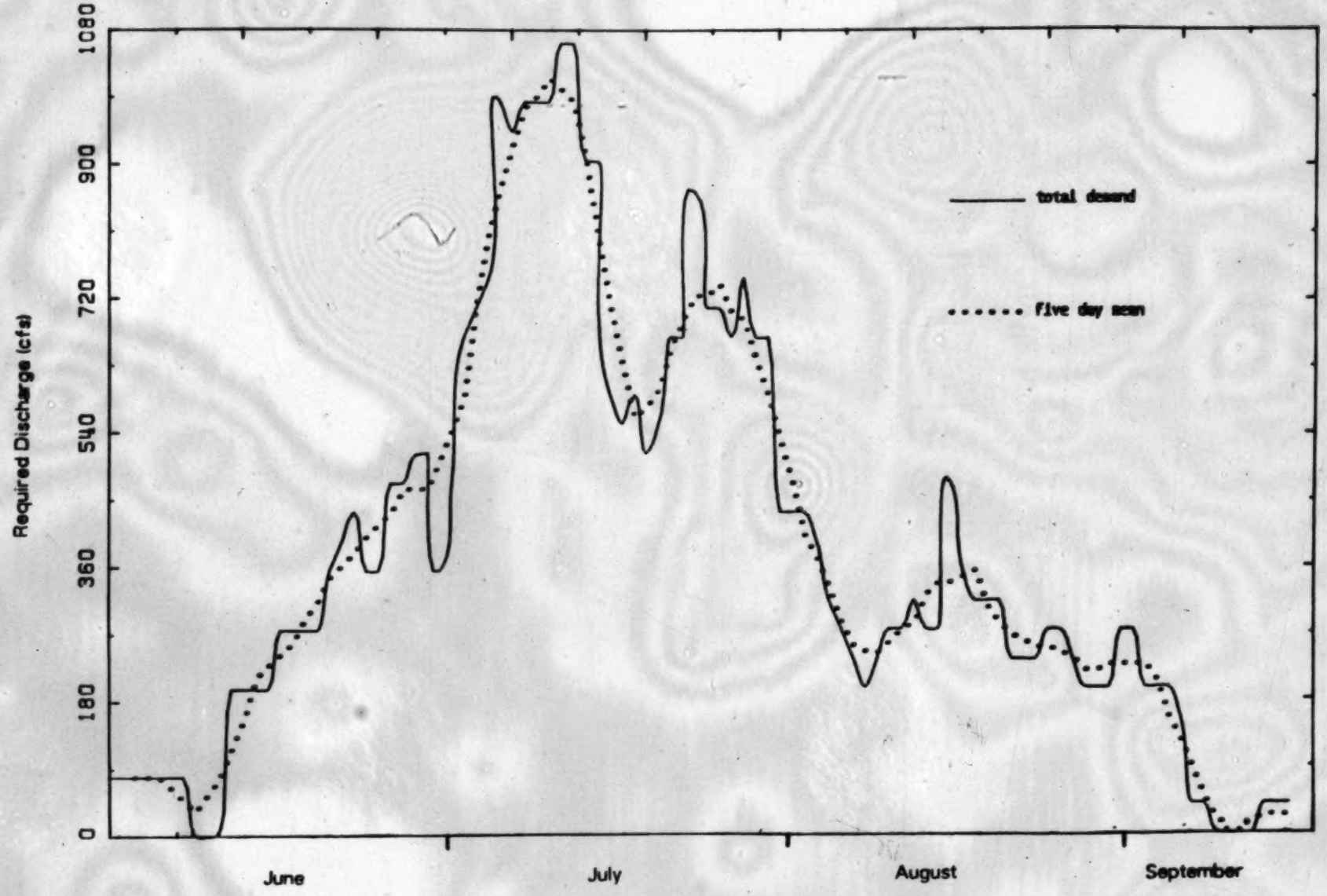


Figure 6-11 Total demand and five day running mean curves for the LNID south region 1978.

requirements are 1061 cfs, an amount equal to the peak flow for the unaltered 1977 simulated flow curve. Gross diversion requirements, defined by the area under the running mean curve, are 72830 acre-feet. This is only 1 percent less than the 1977 gross diversion. A review of Figure 6-12 demonstrates only minor variations between the 1977 and 1978 running mean curves. However, close scrutiny of several factors indicates that the demand curve for 1978 is not that far out of line.

The April precipitation of 3.52 inches insures the assumption of high initial soil moisture levels is reasonable. Moisture conditions on May 1st were probabaly very close to field capacity. Actual water use by most of the crops in May is low (see Table 6-2) therefore most of the May rainfall (3.76 inches) either percolated to the water table or was lost as runoff. At the end of May, soil moisture levels were quite high, consequently the 1978 demand remained below the 1977 level for the first 15 to 20 days of June. However, June of 1978 was hot and dry, with only 0.47 inches of rain. None of this fell prior to the 18th, so water use, and irrigation demand responded. All of the forage and grain crops used between 4.4 and 6.7 inches of water in June, therefore the peak late June-early July irrigation period is very pronounced. This peak is somewhat sharper than that of 1977, because of a healthy rain on July 5th. The rapid demand drop off on July 6th is a reflection of this event. However, the drop only effects those crops

being irrigated on July 6th. Crops irrigated or partially irrigated prior to the 6th(this included most of the grains and forages), receive only minor benefits from the July 5th rainfall.

The above discussion gains credence if the following is considered. Even if May rainfall had brought soil moisture conditions to field capacity, June moisture use by forages was 6.7 inches, and the major grain crops, 4.6 inches. All of these crops, amounting to 88.1 percent of the total acreage, require full irrigation in late June. Therefore, most of the peak demand was met by July 5th, and the rainfall of that date only served to lower the peak a day or earlier than it would otherwise have dropped.

One other major factor should be considered. If the management practices of section 6-3 of this report were applied to 1978, the peak demands and the total demand would be much lower. Under approach 2, with barley crops being planted in June, it is probable that July rainfall would have met most of the moisture deficits. Only small irrigation applications would have been necessary. It is quite possible that rainfall would have been fully adequate, particularly for silage barley planted near the middle of June (over 6.5 inches of rain fell in August, 1978).

6.4.2 Monthly Consumptive Use by the Major Crop Groups, 1978

The 1978 consumptive use values for the major crops grown in southern Alberta are presented in Table 6-2. These

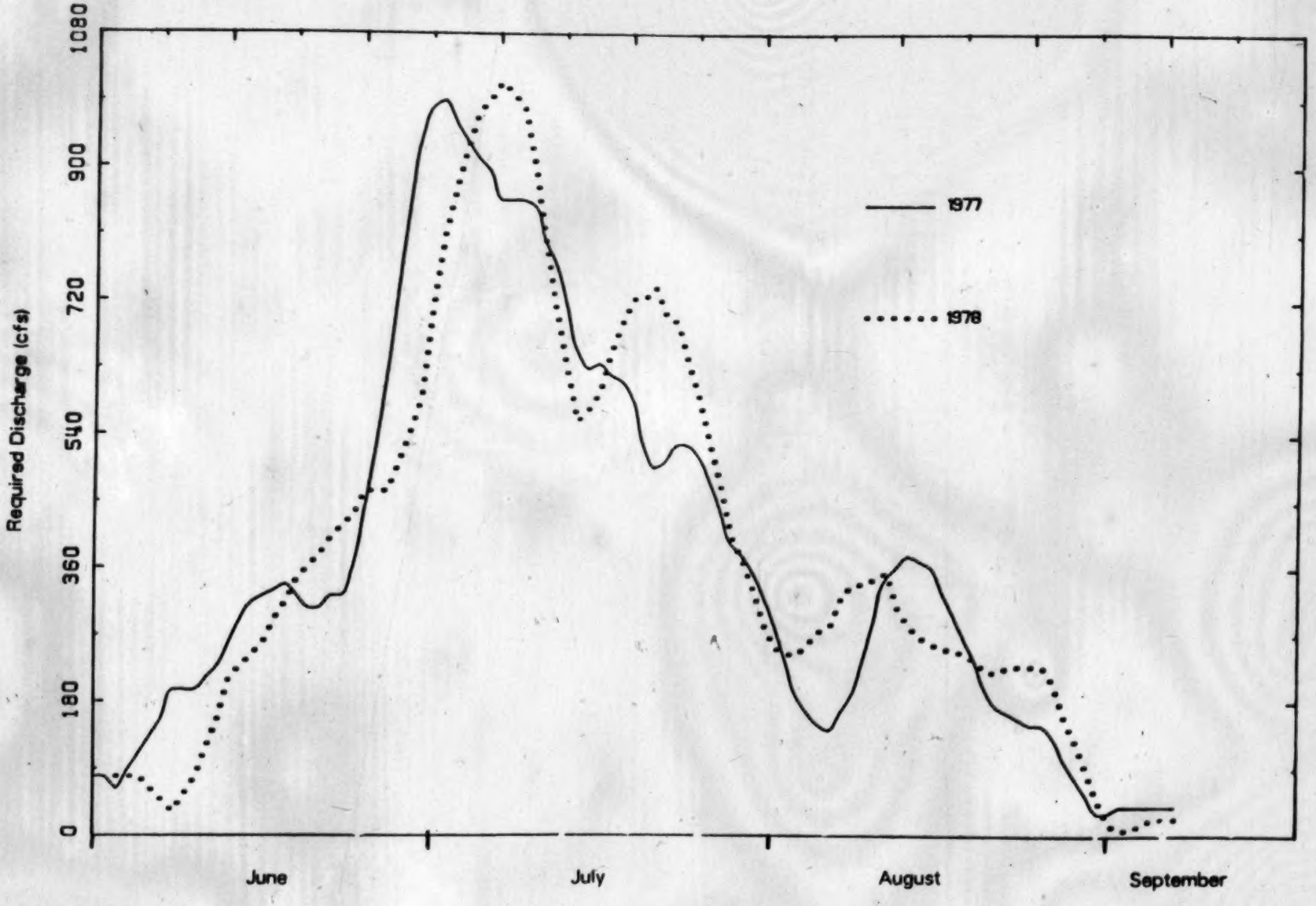


Figure 6-12 Comparison of the five day mean curves for 1977 and 1978.

values were determined in the same manner as those of 1977.

6.5 Conclusions

Consumptive use values and headgate requirements for the LNID for 1977 and 1978 have been determined with the TIMS irrigation model. The findings indicate that for optimal irrigation practices to be applied on a district basis, some management approach is required to keep peak water demand at reasonable levels. A lowering of peak demand levels by 18.6 percent is achieved with a sample management program. The implication of this saving, in terms of required conveyance system capacity , is pointed out.

Discussion in section 6.3 indicates that without a management program designed to lower peak demands, optimal irrigation requirements can be very high even in years of high total precipitation. The timing of summer rainfall on irrigated land is critical. Little value is derived from precipitation that does not arrive when storage is available in the soil profile.

7. SUMMATION

Current irrigation practices of two test areas in the Lethbridge Northern Irrigation District were monitored and the total water consumption for each was recorded. A water demand for these two areas was simulated with a computer program, based on the known optimal water requirements for individual crop types. The simulated requirements were lower than the actual consumption for both areas: Area 1-2 had a simulated requirement that was nearly 7 percent lower than actual consumption; Area 3-4 had a net benefit of almost 11 percent. The lower net conservation value for Area 1-2 is due to the high conveyance efficiency of the concrete lined lateral serving the area. Operational losses would be lower for this region because of the lining; therefore one would expect less benefit from a conservation program. This can be attributed to the principle of diminishing returns. The reach serving Area 3-4 is an earth canal with major seepage losses (these are listed in table 5-3). Therefore, the same principle indicates a greater net conservation can be expected, since there is more room for improvement. Information on what portion of irrigation laterals are lined, or maintained at efficient conveyance levels is not available. For this reason, a weighted average of the demand change between the two areas could not be reasonably attempted. However, this study concludes the net conservation benefit of implementing computer assisted irrigation water management would approach the Area 3-4

value. This is expected because reported efficiency levels for southern Alberta are in the same range as that of Area 3-4.

Peak irrigation demands were discussed in sections 5.3.1 and 6.3. The high demand levels were a result of the simultaneous occurence of peak demands for the 3 most common crops; alfalfa, barley and wheat. To lower the peak demand, the irrigation practices and planting dates for these 3 crops were manipulated, within defined safe guidelines, to the greatest degree possible. Significant attenuation of demand peaks was achieved. The success was due to a quantitative analysis, with a computer management program, that insured optimal use of the water supply within a criteria that prevented any adverse effects to the farmers or the district. The same type of attenuation with a qualitative, 'intuitive' management strategy is not possible. Therefore, this typre of water demand manipulation is not viable for Alberta irrigation districts since all are operated by field staff in an 'intuitive' manner.

Aspects of return flow were discussed in sections 2.3.1 and 5.3.2. Return flow volumes can be dramatically reduced with a district scheduling program based on crop water requirements. Current return flow levels are in the 15-16 percent range for 'dry' years. These values could be lowered to a quantity associated with on-farm spillwater: ie. the district would not spill any major volume. Quantification of the true reduction in return flow levels was not possible

within the bounds of the work performed here. However, the need for maintaining high flow levels in the system to meet anticipated demands is eliminated. In 'wet' years, spillwater levels may rise due to precipitation events that preempt irrigations for which water is already in transit. However, the impact of spilling channel storage quantities in a 'wet' year would not be significant since the water supply will be far greater than the demand.

7.1 Final Conclusions

(1). Integration of farm and district scheduling programs into a management concept is an viable approach to optimizing irrigation water supply usage. Advantages to the irrigation districts will include:

(a). lower seepage losses, with consequential reductions in soil salinity problems;

(b). lower return flow volumes;

(c). efficient conveyance system operation;

(d). a lower conveyance system capacity requirement, therefore initial construction and maintenance costs will be lower.

Advantages for the farmers include:

(a). more efficient use of water, energy, equipment and labor;

(b). less chance of saline buildup associated with a raised water table due to over-irrigation;

(c). a better assurance of supply, due to improved

efficiency;

(d). increases in crop yield - a number of researchers (Hobbs et al, 1978 and others) have proven crop quality and quantity rises with proper irrigation scheduling.

(2). Computer simulation methods make large areal applications of crop and district scheduling procedures viable. Simulation methods can also be used to test the practicality of management alternatives to cope with a number of situations.

(3). The computer scheduling method applied here demonstrated:

(a). a possible net water conservation level of 11.25 to 22.7 percent;

(b). a reduction in peak demand of 18.6 percent with simple management-farm coordination practices.

7.2 Implementation of Computer Supported Management

Computer supported management is technically feasible - the french have demonstrated far greater capabilities(*Regulation Dynamique*, no date). The primary obstructions to application in Alberta would be social resistance of the farmers and a lack of properly trained field staff. Similar resistance by the districts field personnel will likely be minimal - Lethbridge Northern ditchriders involved with this study took an active interest and were quick to utilize the weirs as water control tools.

Efficient control of a water supply directly implies the need for a network of flow measurement structures. Without such a network, field staff cannot reasonably be expected to route flows with the degree of accuracy required. The cost of a flow measurement network would be minor if it is integrated into the rehabilitation program currently underway.

BIBLIOGRAPHY

Bird,J.B. *THE NATURAL LANDSCAPES OF CANADA*. Toronto:Wiley Publishers of Canada 1972.

Buchheim,J.F. and Ploss,L.F. *Computerized Irrigation Scheduling Using Nuetron Probes*. U.S.B.R. presented at the Annual Meeting ASAE., Raleigh, North Carolina, June 26-27, 1977

Bucheim,J.F., Ploss,L.F. and Brower,L.A. *Water Systems Users Management Guide*. U.S. Department of the Interior, Water and Power Resources Service, Report number REC-ERC-80-3, April 1980

Campbell,M.D., Buchheim,J.F. and Brower,L.A. *Wide Area Irrigation Scheduling for Efficient Use of Water*. Proceeding:Second World Congress on Water Resources, New Delhi, India December 12-16, 1975.

Chow,V.T. *HANDBOOK OF APPLIED HYDROLOGY*. Toronto:McGraw-Hill Book Company 1964.

Critchfield,H.J. *GENERAL CLIMATOLOGY*. 3rd ed. Englewood Cliffs:Prentice-Hall, INC. 1974.

Hansen,V.E., Israelson,O.W. and Stringham,G.E. *IRRIGATION PRINCIPLES AND PRACTICES*. 4th ed. Toronto:John Wiley and Sons,INC. 1980.

Hardy,W.G.ed. *ALBERTA - A NATURAL HISTORY*. Edmonton:M.G. Hurtig,Publishers 1975.

Henderson,F.M. *OPEN CHANNEL FLOW*. New York: MacMillan Publishing Co.,INC. 1966.

Heywood, R.T., *Irrigation Water Requirement for the South Saskatchewan River Basin*. Unpublished Report. Farm Irrigation Services Branch, Irrigation Division, Alberta Agriculture - undated.

Hillel,D. *APPLICATIONS OF SOIL PHYSICS*. Toronto:Academic Press 1980.

Hoel,P.G. *ELEMENTARY STATISTICS*. 4th ed. Toronto:John Wiley and Sons,INC. 1976.

Hobbs,E.H. and Krogman,K.K. *Irrigation Scheduling: An Example of Research-Extension-Grower Cooperation*. AGRICULTURAL INSTITUTE REVIEW, January-Febuary,1968.

Hobbs, et al. *Water use in a Southern Alberta Irrigation District*. Transactions of American Society of Agricultural Engineers(vol.6,no.3)1963.

Hobbs, et al. *Observed and Estimated Evapotranspiration in Southern Alberta*. Transactions:ASAE vol.11,no.4,1968.

Hobbs, et al. *Frequent Light Irrigation Scheduling to Improve Efficiency of Water Use*. CANADIAN AGRICULTURAL ENGINEERING,vol.20,no.2, December,1978

Jensen,M.E. and Wright,J.L. *The Role of Evapotranspiration Models in Irrigation Scheduling*. Transactions of ASAE. 1978

Kocaoglu,S.S. and Pettapiece,W.W. *Lethbridge Area Soils Map*. Agriculture Canada and Alberta Institute of Pedology. No. M-8-3, 1980

Krogman, K.K. and Hobbs, E. H. *Scheduling Irrigation to Meet Crop Demands*. Canada Department of Agriculture Publication No. 1590, 1976

Oosterveld,M. *Canada-French Scientific Exchange Visit*. Internal report, Agriculture Canada Research Station, Soil Science Section, 1980

Oosterveld,M. and Chang,C. *Empirical Relations Between Laboratory Determinations of Soil Texture and Moisture Retention*. CANADIAN AGRICULTURAL ENGINEERING, vol.22, no.2, December,1980.

Ploss,L.F., Buchheim,J.F. and Brower,L.A. *Irrigation Project*

Distribution System Scheduling. U.S.B.R.(presented at the Irrigation and Drainage Specialty Conference, ASCE., Albuquerque, New Mexico, July 17-20, 1979).

Proceedings of National Conference on Managing Irrigated Agriculture to Improve Water Quality. Colorado State University May 16-18, 1972.

Environment Council of Alberta, *Public Hearings on Management of Water Resources within the Oldman River Basin Report and Recommendations*. August 1979

Foth, H.D. and Turk, L.M., *Fundamentals of Soil Science*. New York:John Wiley and Sons, INC. 1972

Hillel, D., *Applications of Soil Physics*. New York:Academic Press 1980

Manz, D.H. and Verschuren, J.P. *Performance Evaluation of Irrigation Water Storage, Transfer and Application Processes*. presented at CSAE Annual Meeting, Vancouver, B.C. July 11-15th, 1982.

Phread, D.E.H. ed. *Agricultural Chemistry*. New York:D. Van Nostrand Company,INS. 1950

Rapp, E., van Schaik, J. C. and Khanal, N.N. *A Hydrologic Budget for a Southern Alberta Irrigation District*. CANADIAN AGRICULTURAL ENGINEERING, vol. 11, no. 2,November, 1969

Rissel, W.E. *Soil Conditions and Plant Growth*. London:William Clones and Sons, Limited 1973

Robinson,C.P. *1977 Return Flow for Irrigation Districts in Alberta*. Water Survey of Canada, 1978

Regulation Dynamique.Societe du Canal de Provence, Tholn, France, undated.

Schuler, R.H. *Oldman River Basin Preliminary Irrigation and Water Demand Study to the Year 2005*. in: Oldman River Flow Regulation Preliminary Planning Studies, Volume II,

Water Demand Assessment. Alberta Environment Planning Division, 1976

Smith,C.D. *HYDRAULIC STRUCTURES*. Saskatoon:University of Saskatchewan Printing Services 1978

Stanley/SLN Consulting, Oldman River Basin Irrigation Studies *Summary Report*. Lethbridge, April 1978

Swarner,L.R., Buchheim,J.F. and Goar,J.F. *Scheduling Farm Irrigation Demands Throughout Project Distribution Systems*. U.S.B.R.(presented at Eighth Technical Conference on Irrigation Drainage and Flood Control, Phoenix, Arizona. September 26-29, 1979).

Szabolcs, I. *Review of Research on Salt-Effected Soils*. United Nations Educational, Scientific and Cultural Organization. Paris, 1979

Thorne, D.W. and Thorne, M.D., *Soil, Water and Crop Production*. Wesport: AVI Publishing Company, INC. 1979

Tokarsky, O. *Hydrogeology of the Lethbridge-Fernie Area*. Alberta Research Council Earth Sciences Report 74-1, 1974

Viessman, W.Jr., Knapp, J.W., Lewis, G.L. and Harbaugh, T.E. *INTRODUCTION TO HYDROLOGY*. New York: Harper and Row, Publishers 1977.

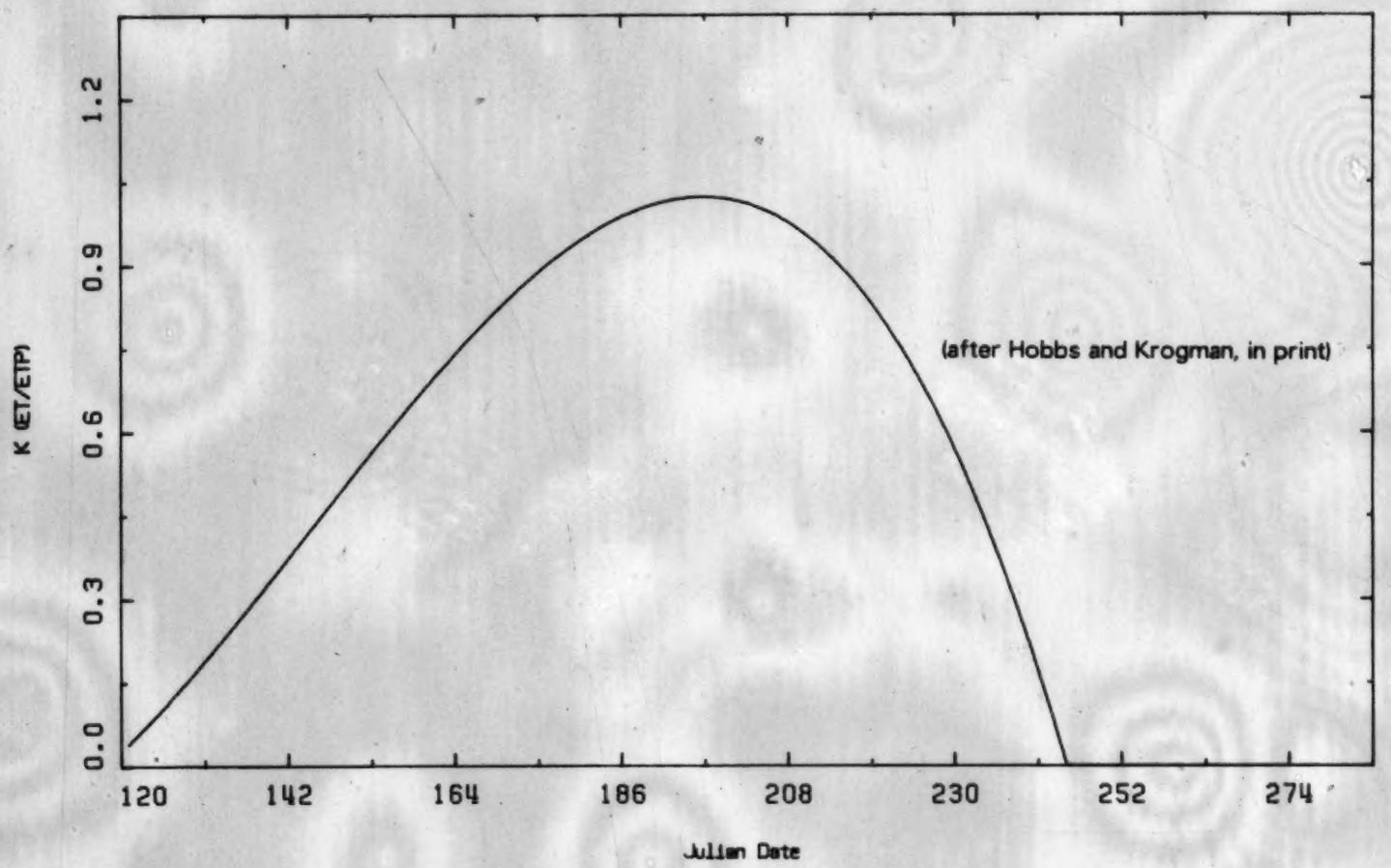
Wyatt,F.A. *Soil Survey Map of MacLeod Area*. Ottawa:Topographical Survey of Canada 1924

Wright,J.L. and Jensen,M.E. *Development and Evaluation of Evapotranspiration Models for Irrigation Scheduling*. Transactions of ASAE. 1978.

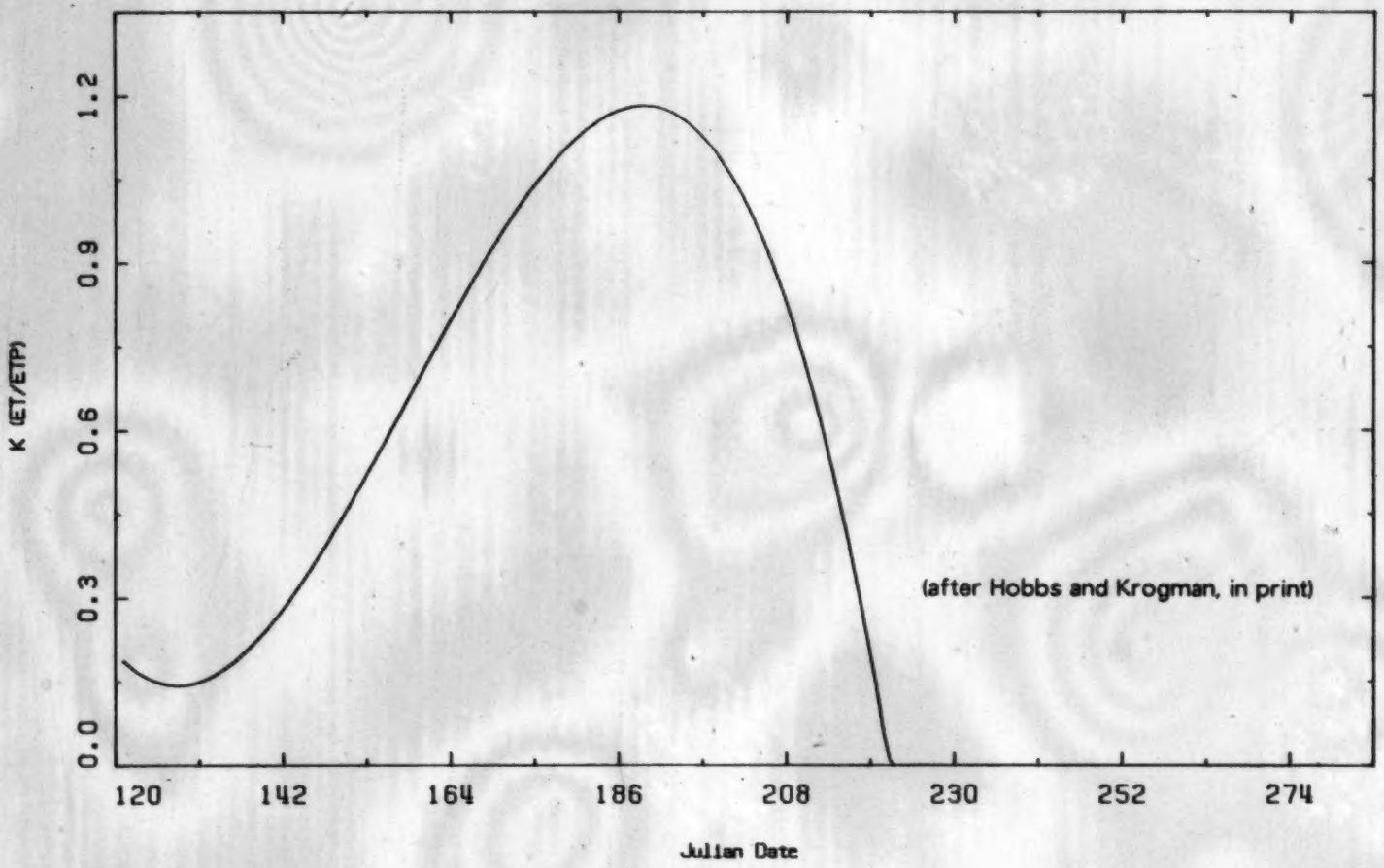
Wright, J. L. *Crop Coefficients for Estimates of Daily Crop Evapotranspiration*. Proceedings of the Irrigation Scheduling Conference for Water and Energy Conservation in the '80s. ASAE Conference, Chicago, Illinois, December 14-15, 1981

APPENDIX A

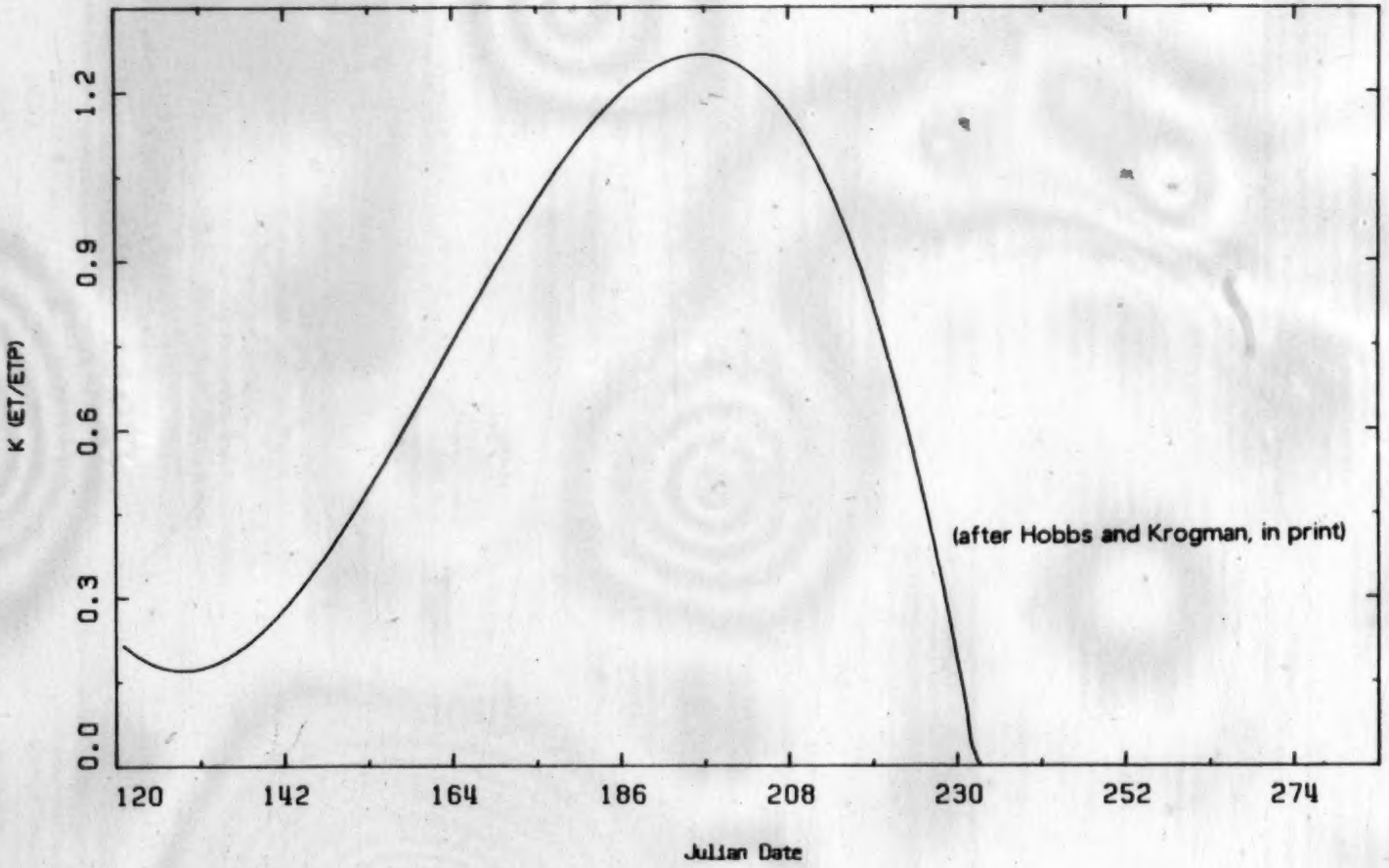
Krogman and Hobbs(1976) developed crop water use curves for common southern Alberta crops. The crop coefficient curves utilized in this study are revisions of the 1976 data (Hobbs, pers. comm., data in print). The following pages contain plots of the revised crop coefficient curves, and are included here with the permission of Agriculture Canada. More detailed information on these curves will be published in a 1983 technical bulletin of the Research Branch, Agriculture Canada. The bulletin is authored by E. H. Hobbs and K. K. Krogman.



HOBBS CROP COEFFICIENT CURVE FOR PEAS



HOBBS CROP COEFFICIENT CURVE FOR BARLEY



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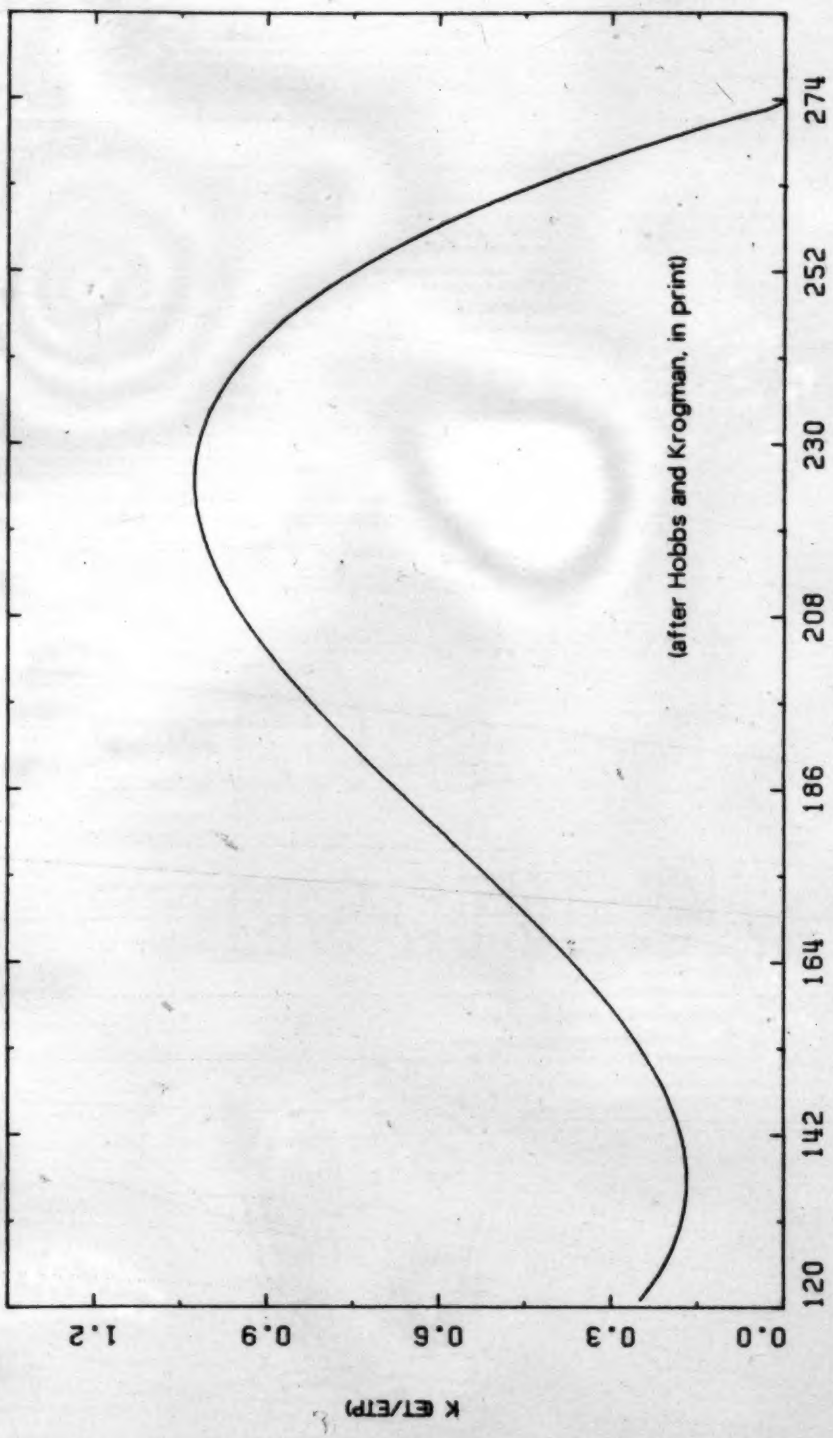

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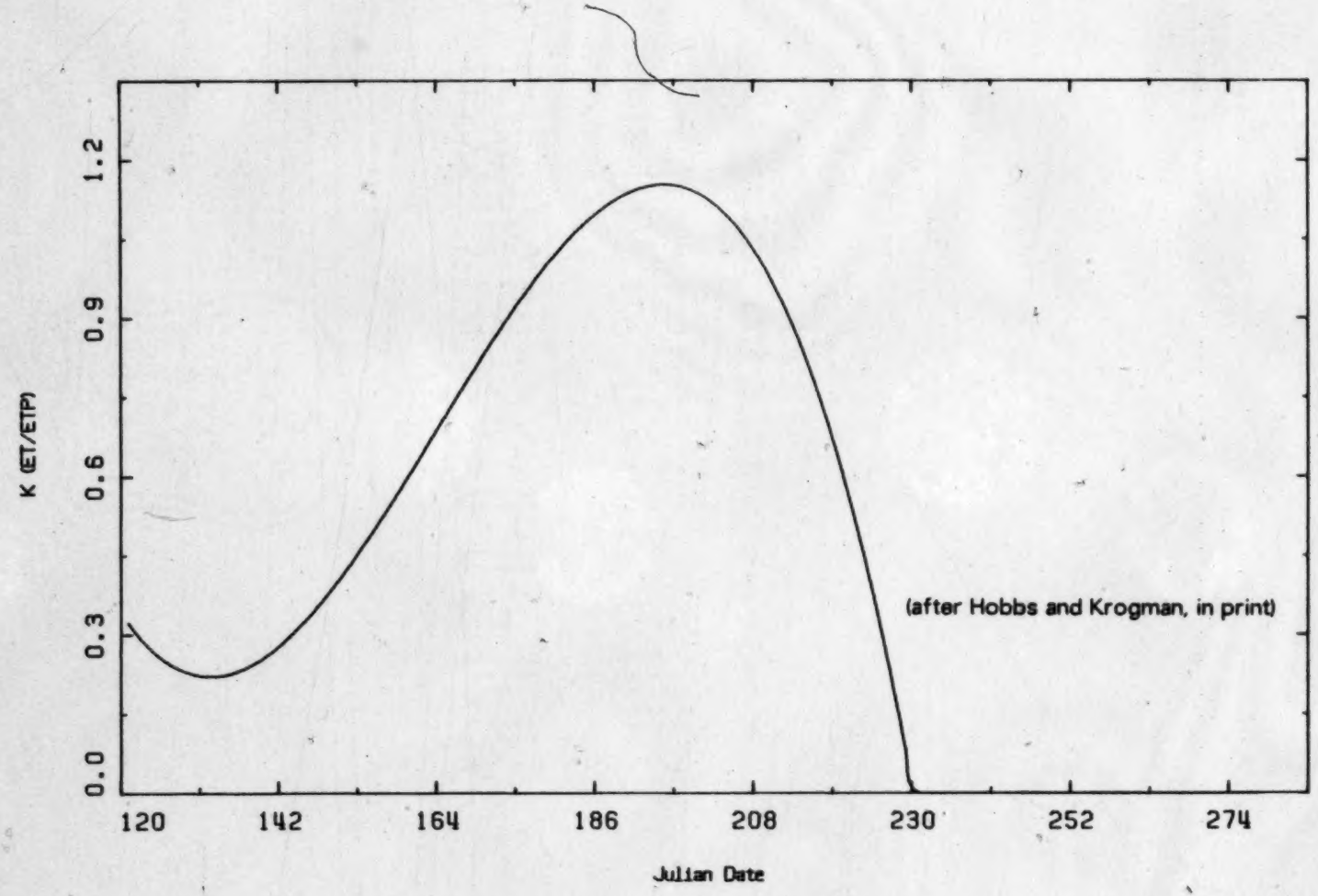
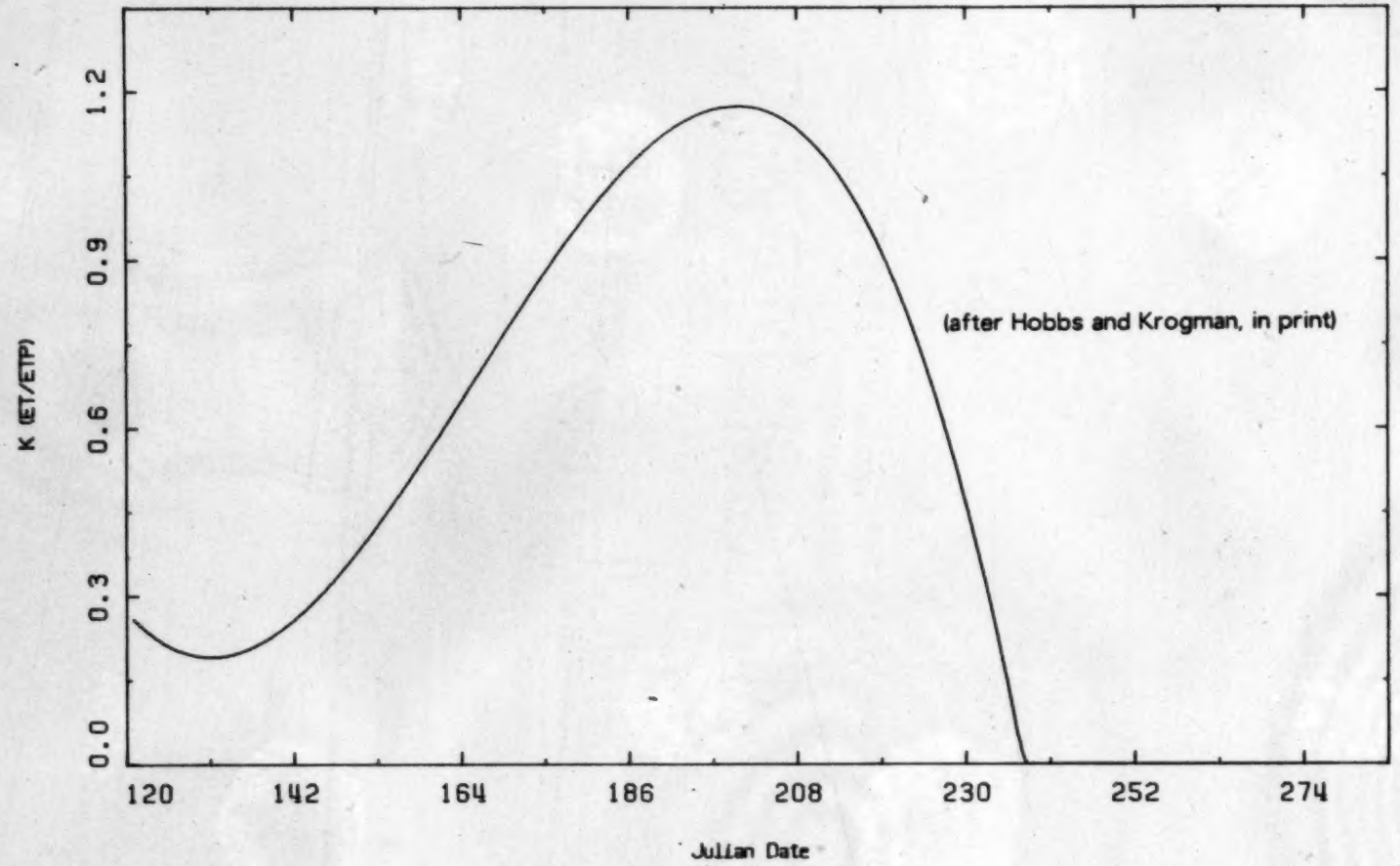


HOBBS CROP COEFFICIENT CURVE FOR RAPE



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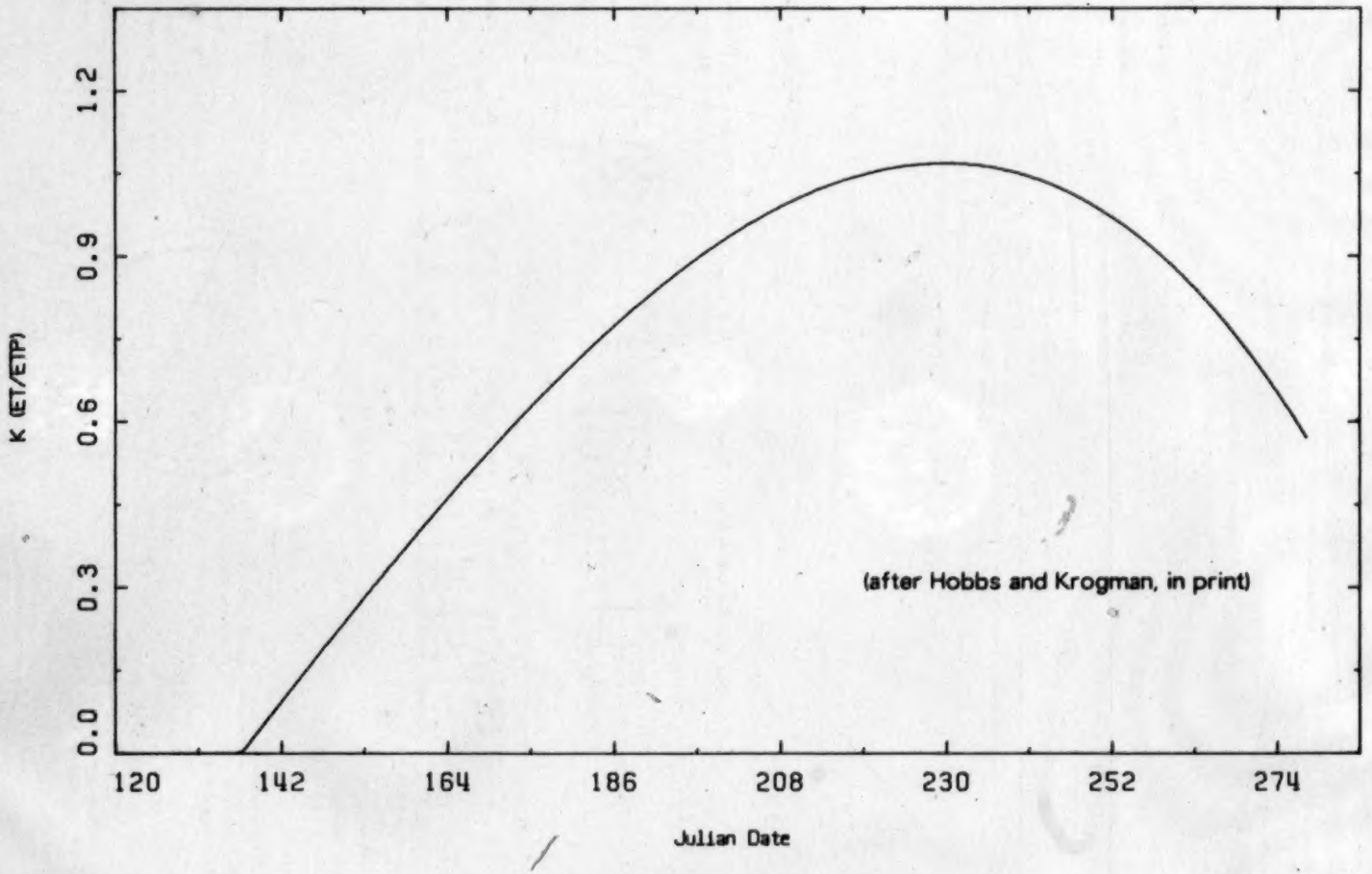

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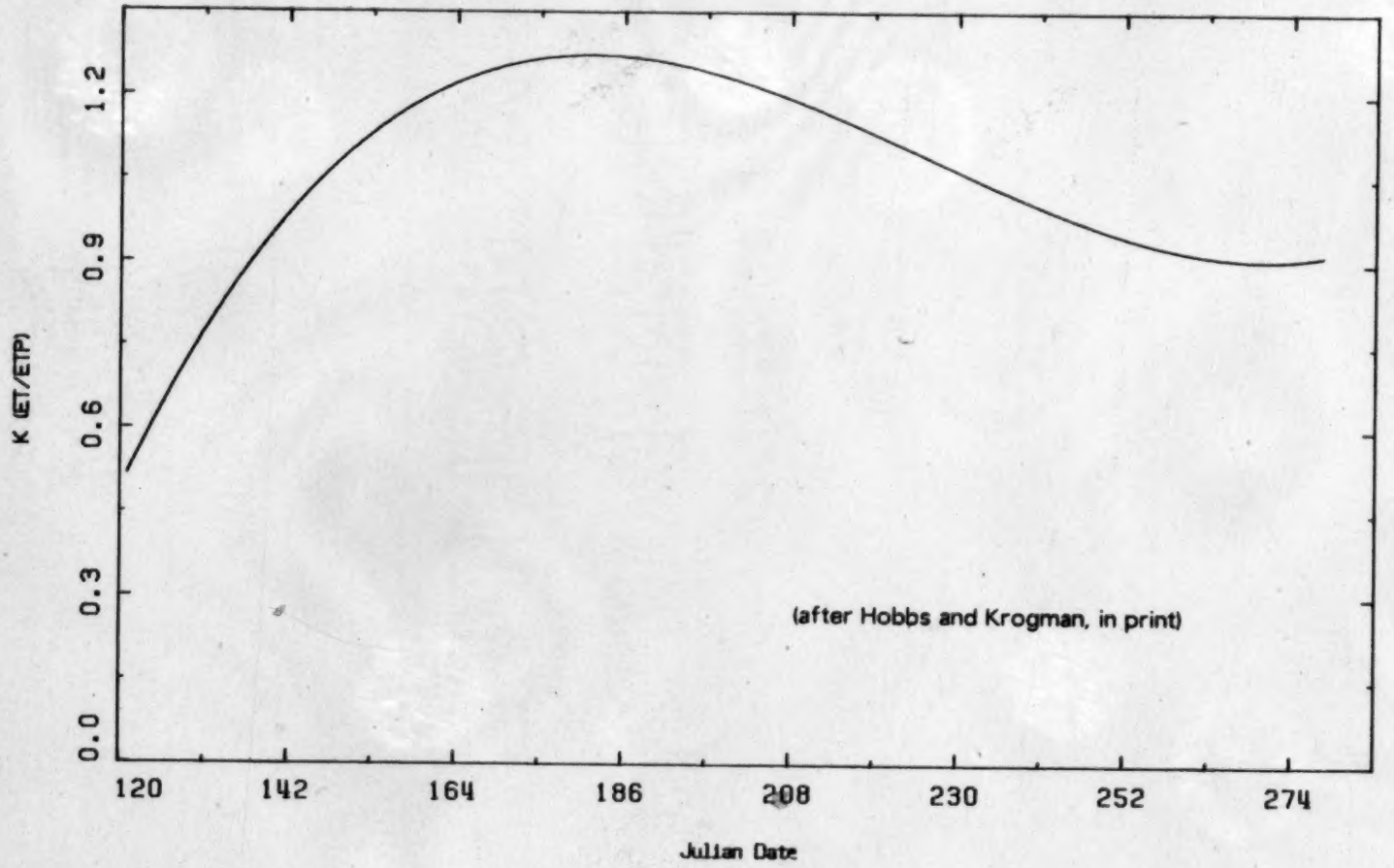

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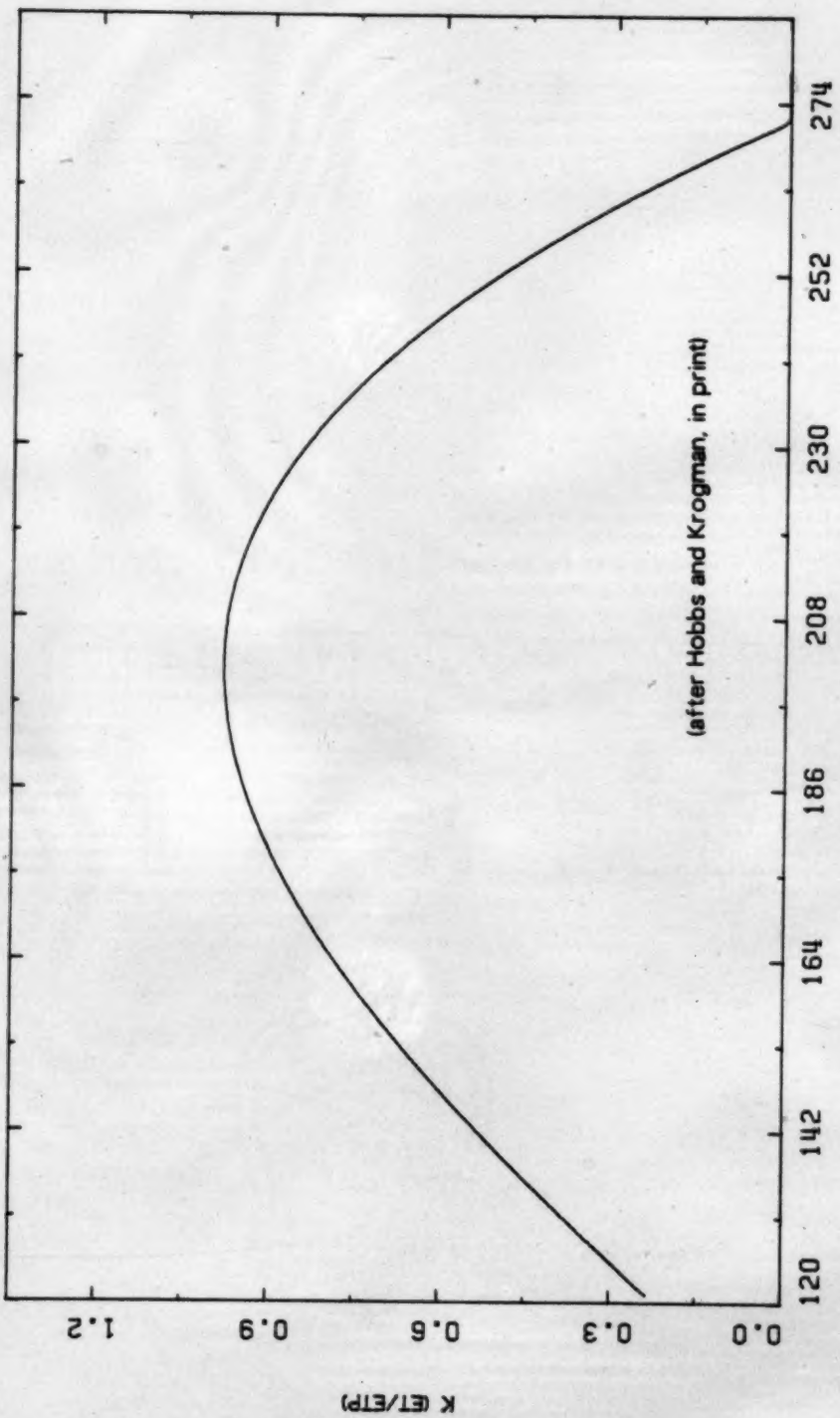

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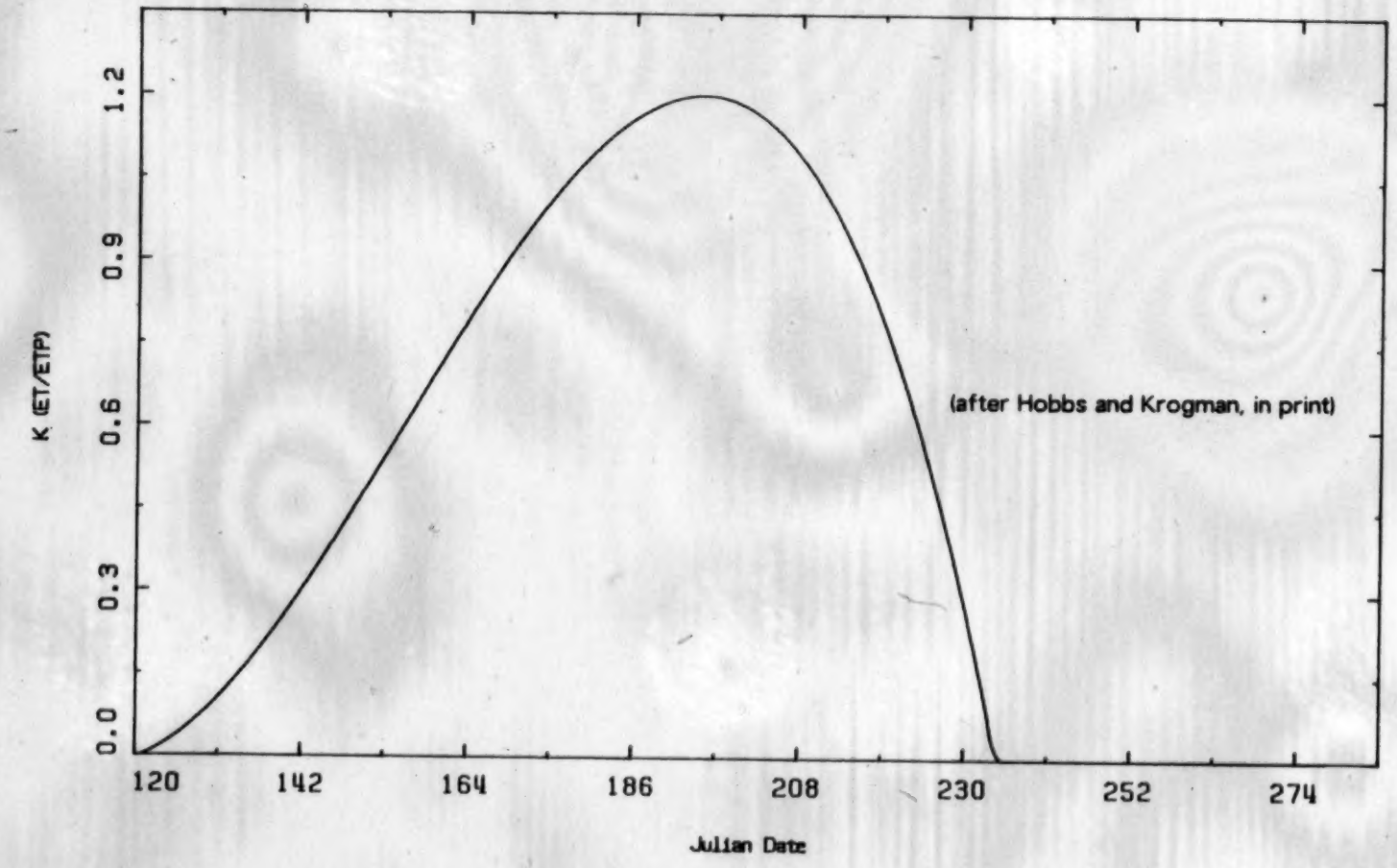

HOBBS CROP COEFFICIENT CURVE FOR WHEAT